US009350996B2

(12) **United States Patent**
Fang et al.

(10) **Patent No.: US 9,350,996 B2**
(45) **Date of Patent: *May 24, 2016**

(54) **METHOD AND APPARATUS FOR LAST COEFFICIENT INDEXING FOR HIGH EFFICIENCY VIDEO CODING**

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(73) Assignee: **GOOGLE TECHNOLOGY HOLDINGS LLC**, Mountain View, CA (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 500 days.

This patent is subject to a terminal disclaimer.

(21) Appl. No.: **13/722,625**

(22) Filed: **Dec. 20, 2012**

(65) **Prior Publication Data**

US 2013/0215969 A1 Aug. 22, 2013

Related U.S. Application Data

(60) Provisional application No. 61/577,898, filed on Dec. 20, 2011.

(51) **Int. Cl.**
H04N 7/26 (2006.01)
H04N 7/30 (2006.01)
(Continued)

(52) **U.S. Cl.**
CPC ***H04N 19/00775*** (2013.01); ***H04N 19/132*** (2014.11); ***H04N 19/136*** (2014.11); ***H04N 19/18*** (2014.11); ***H04N 19/463*** (2014.11); ***H04N 19/70*** (2014.11); ***H04N 19/91*** (2014.11); *H04N 19/46* (2014.11)

(58) **Field of Classification Search**
CPC H04N 19/70; H04N 19/463; H04N 19/00775; H04N 19/132; H04N 19/18; H04N 19/91; H04N 19/46
USPC 348/49
See application file for complete search history.

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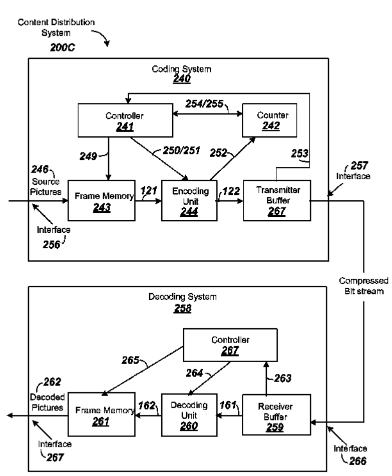
Primary Examiner — Hee-Yong Kim
(74) *Attorney, Agent, or Firm* — Young Basile Hanlon & MacFarlane P.C.

(57) **ABSTRACT**

A method, apparatus, article of manufacture, and a memory structure for encoding and decoding transform unit coefficients is disclosed. In one embodiment, the encoding of the transform unit coefficients is performed by determining if all of the coefficients of a portion of the transform unit disposed on a portion of a scan pattern are zero, setting a flag associated with the portion of the transform unit to a first value if at least one of the coefficients of the portion of the transform unit coefficients disposed on the portion of the scan pattern are non-zero, and setting the flag associated with the portion of the transform unit coefficients to a second value if all of the coefficients of the portion of the transform unit coefficients disposed in the portion of the scan pattern are zero.

26 Claims, 25 Drawing Sheets



(51) **Int. Cl.**

H04N 7/50	(2006.01)
H04N 19/60	(2014.01)
H04N 19/70	(2014.01)
H04N 19/463	(2014.01)
H04N 19/91	(2014.01)
H04N 19/132	(2014.01)
H04N 19/136	(2014.01)
H04N 19/18	(2014.01)
H04N 19/46	(2014.01)

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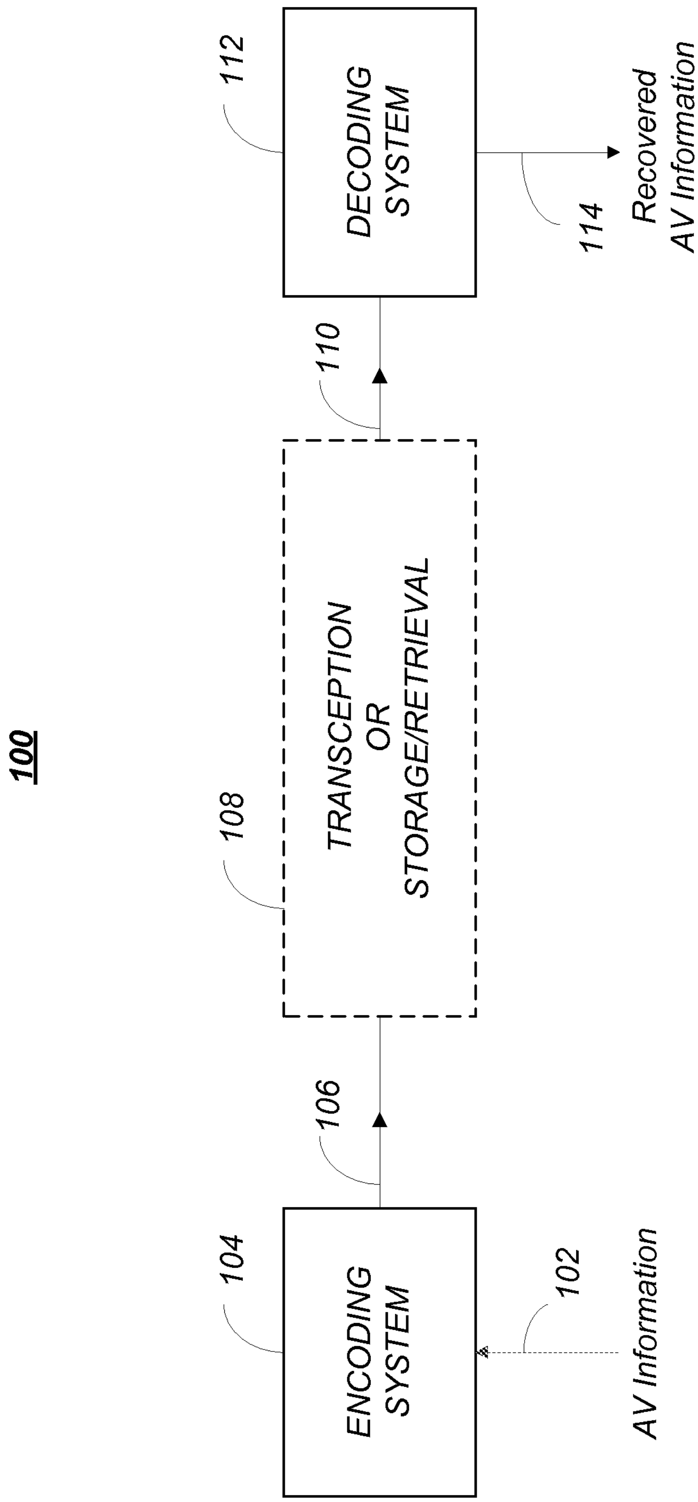


FIG. 1
Prior Art

200A

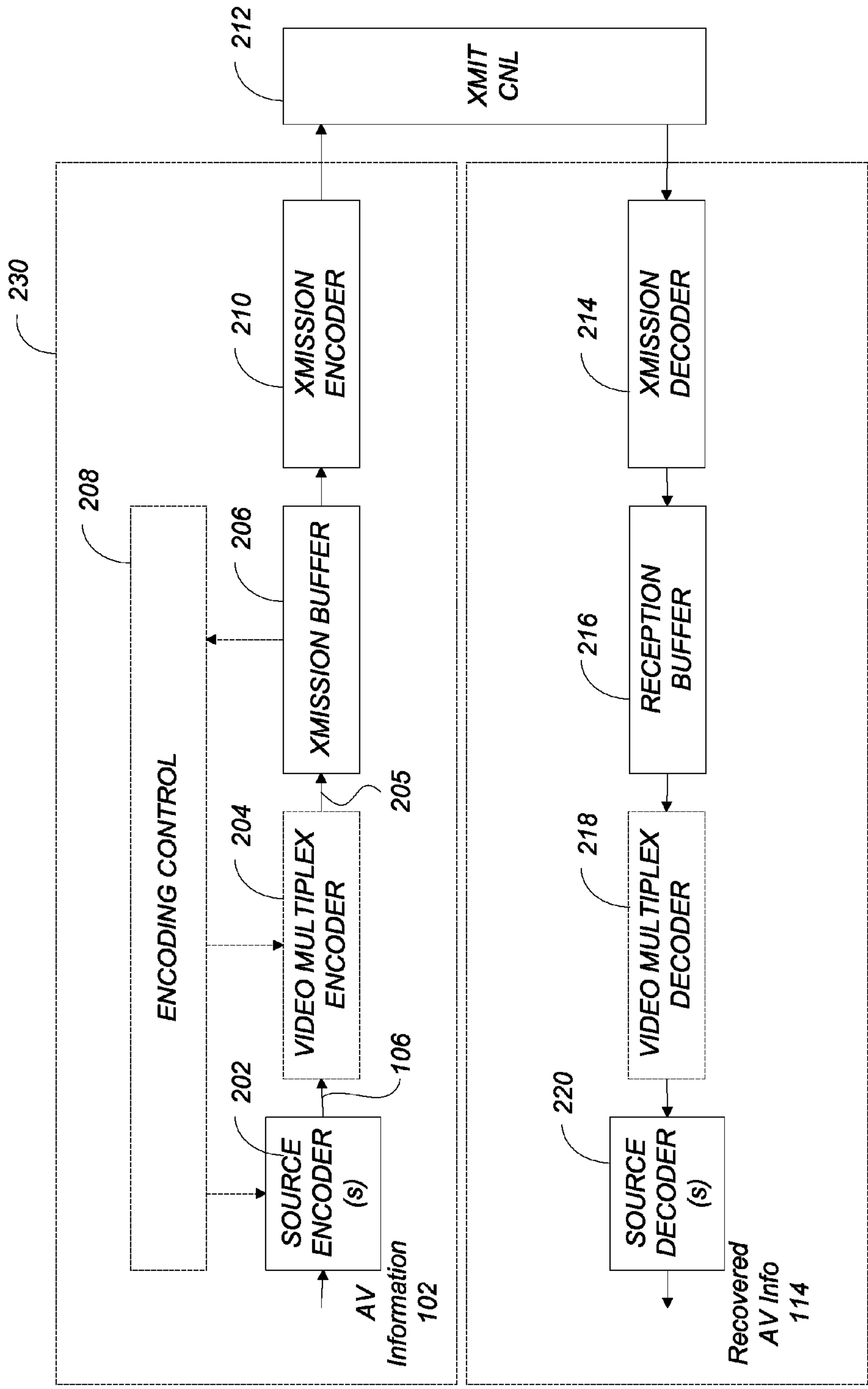


FIG. 2A
Prior Art

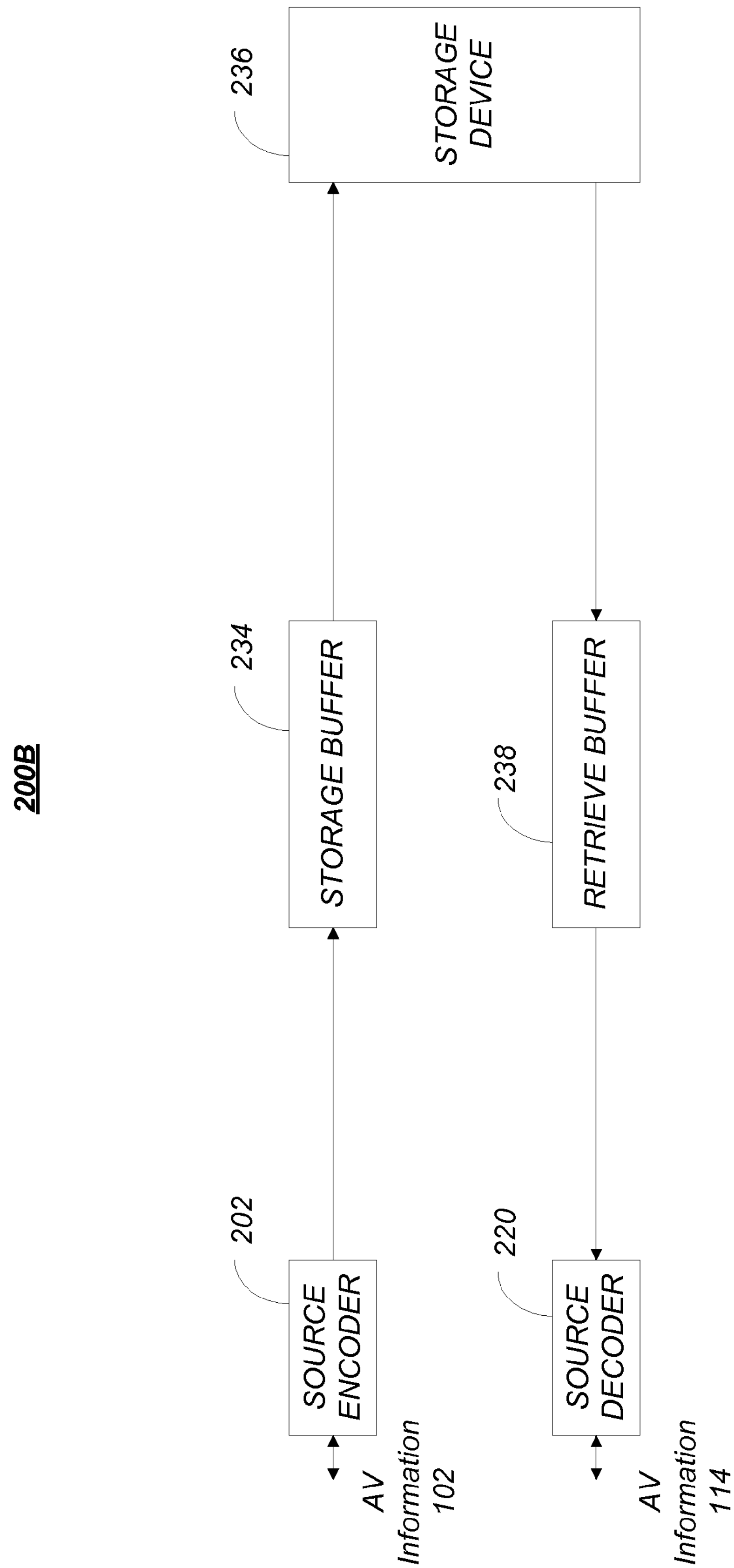
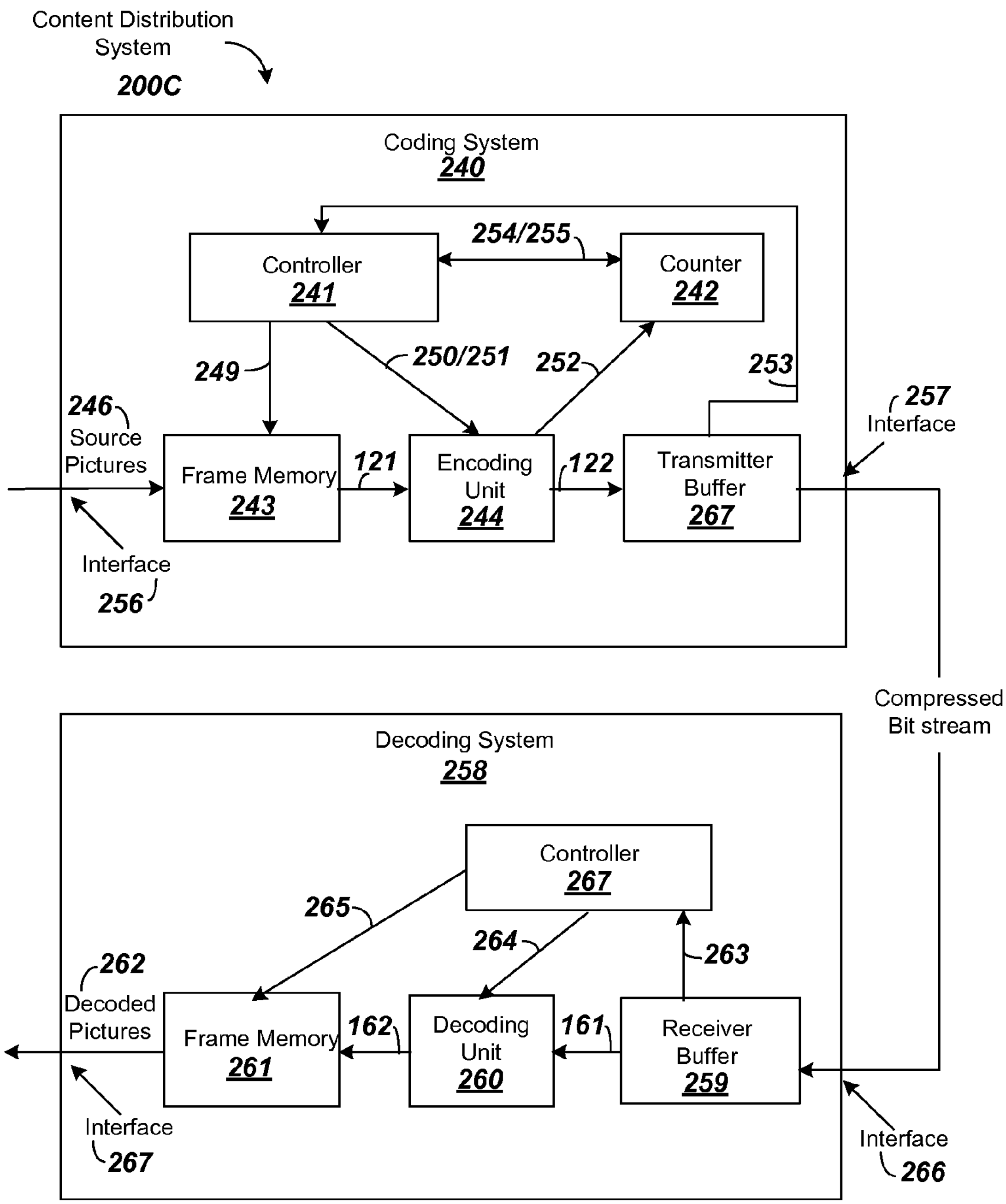


FIG. 2B
Prior Art



Content Distribution System
200C
Coding System
240
Controller
241
254/255
Counter
242
249
250/251
252
253
246
Source Pictures
Frame Memory
243
121
Encoding Unit
244
122
Transmitter Buffer
267
257
Interface
Interface
256
Compressed Bit stream
Decoding System
258
Controller
267
265
264
263
262
Decoded Pictures
Frame Memory
261
162
Decoding Unit
260
161
Receiver Buffer
259
Interface
267
Interface
266

FIG. 2C

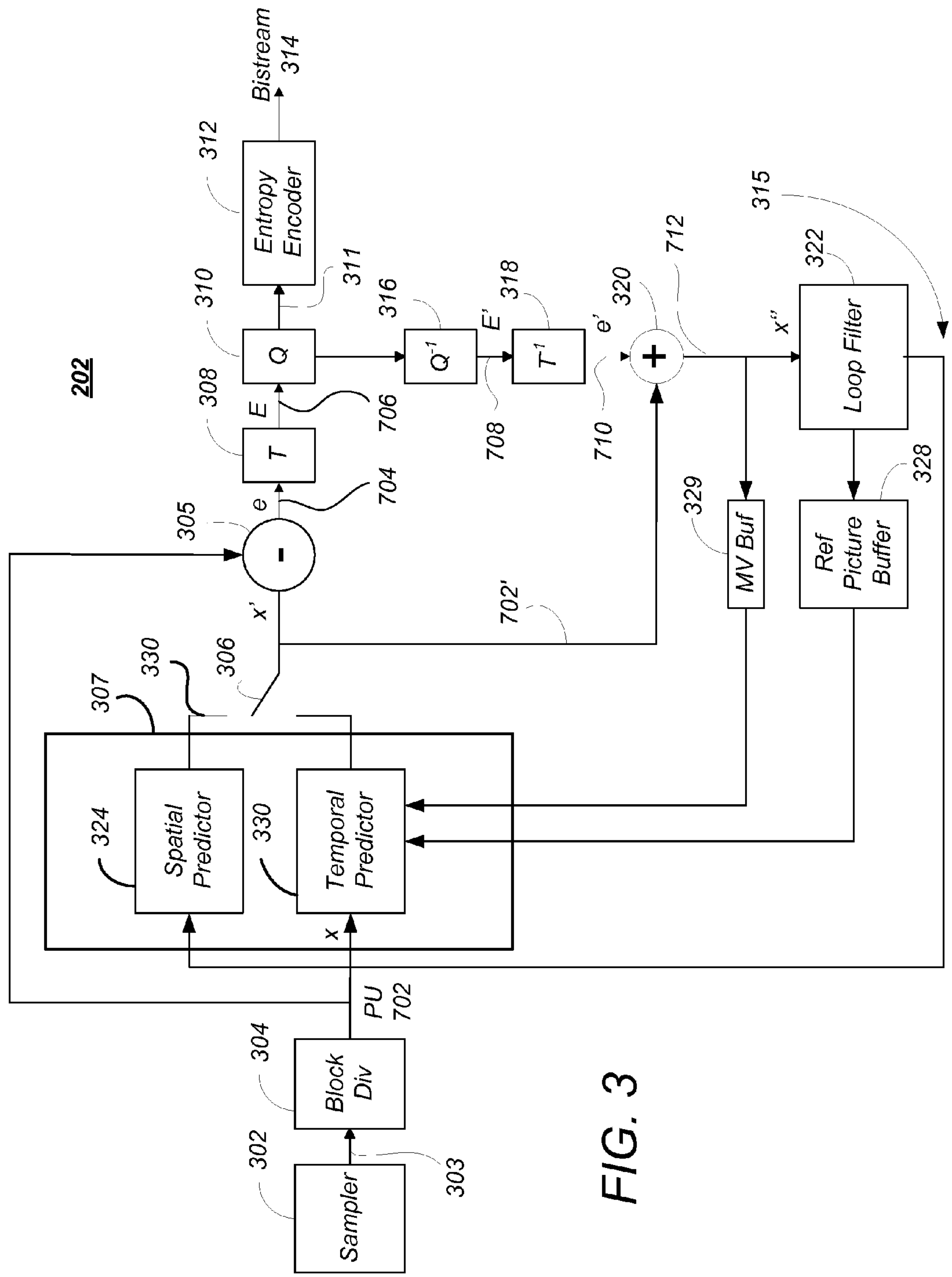

202
Sampler
302
303
Block Div
304
PU
702
x
Spatial Predictor
324
Temporal Predictor
330
307
330
306
x'
305
e
704
T
308
E
706
Q
310
311
Entropy Encoder
312
Bistream
314
Q^-1
316
708
E'
T^-1
318
710
e'
320
712
702'
MV Buf
329
x''
Loop Filter
322
Ref Picture Buffer
328
315

FIG. 3

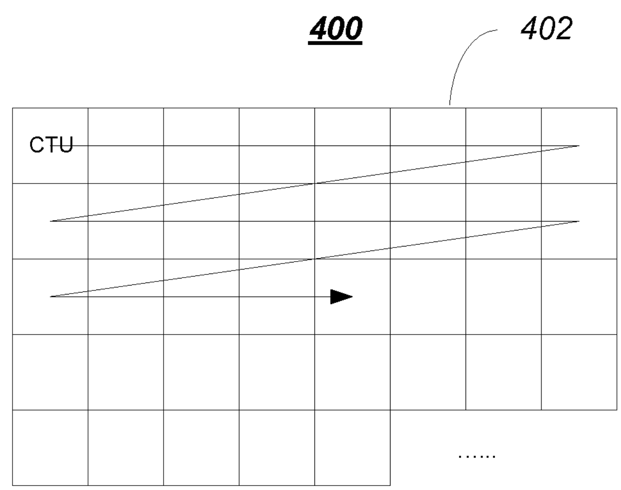


FIG. 4

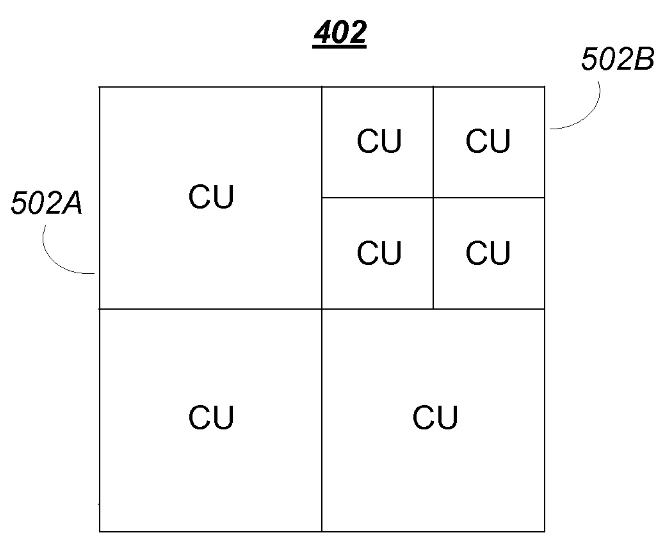


FIG. 5

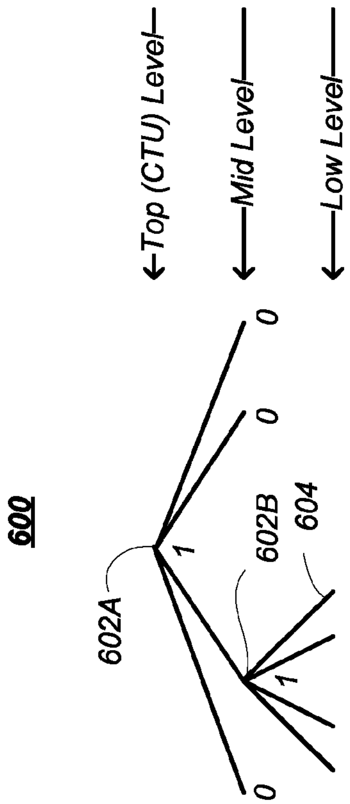

600
602A
602B
604
1
1
0
0
0
Top (CTU) Level
Mid Level
Low Level

FIG. 6

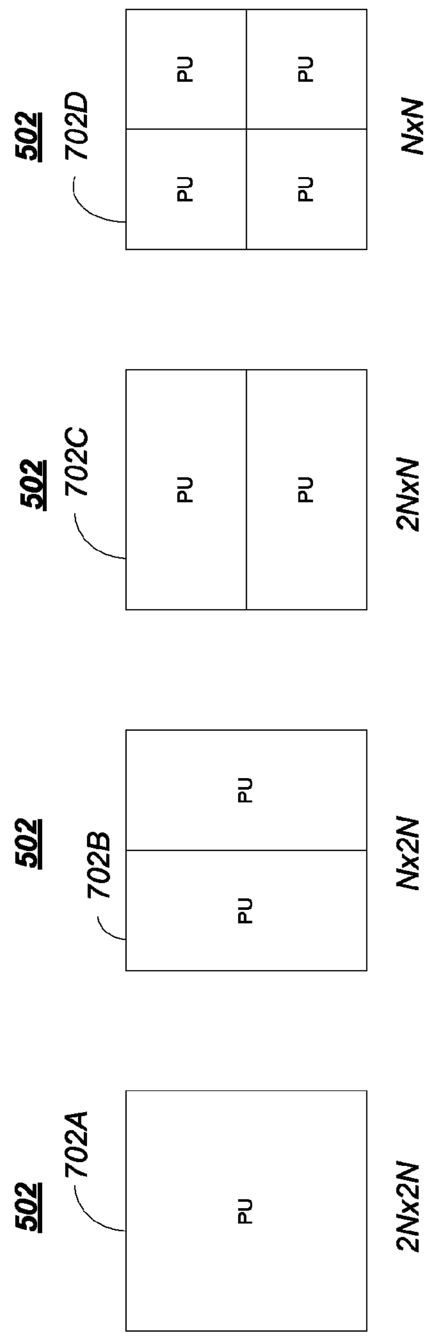

502
702A
PU
2Nx2N
502
702B
PU
PU
Nx2N
502
702C
PU
PU
2NxN
502
702D
PU
PU
PU
PU
NxN

FIG. 7

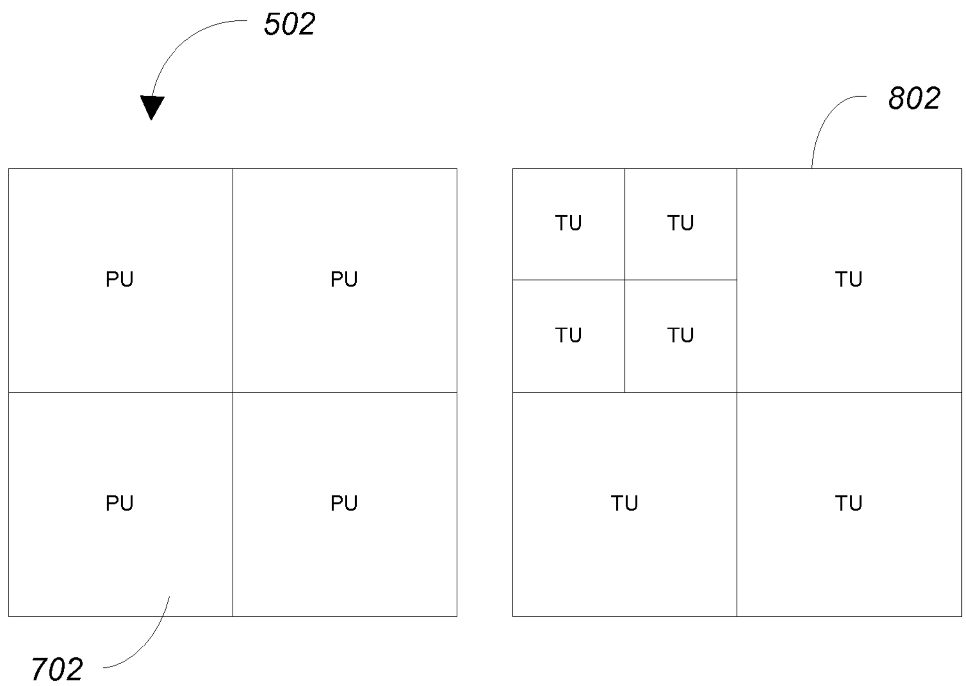

502
802
PU
PU
PU
PU
TU
TU
TU
TU
TU
TU
TU
702

FIG. 8

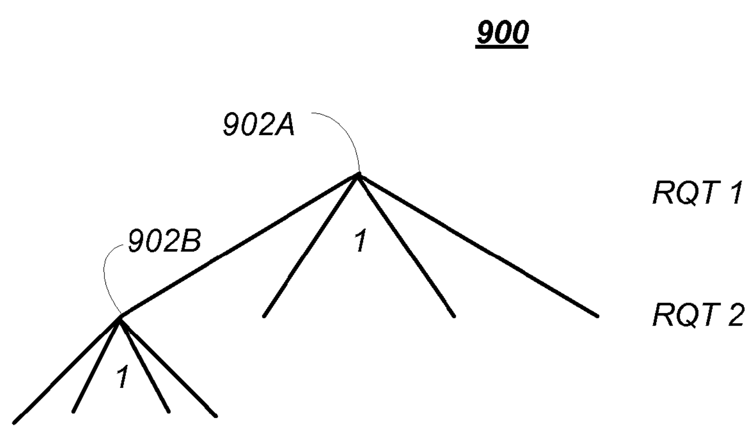

900
902A
902B
1
1
RQT 1
RQT 2

FIG. 9

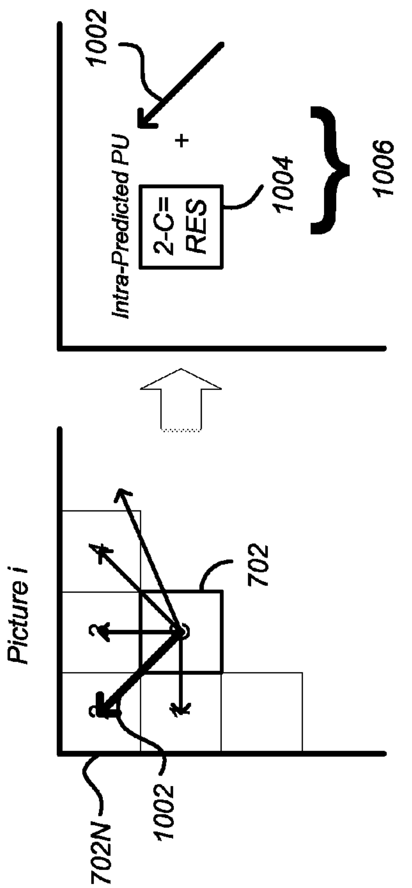

Picture i
702
702N
1002
Intra-Predicted PU
1002
2-C=
RES
1004
1006

FIG. 10

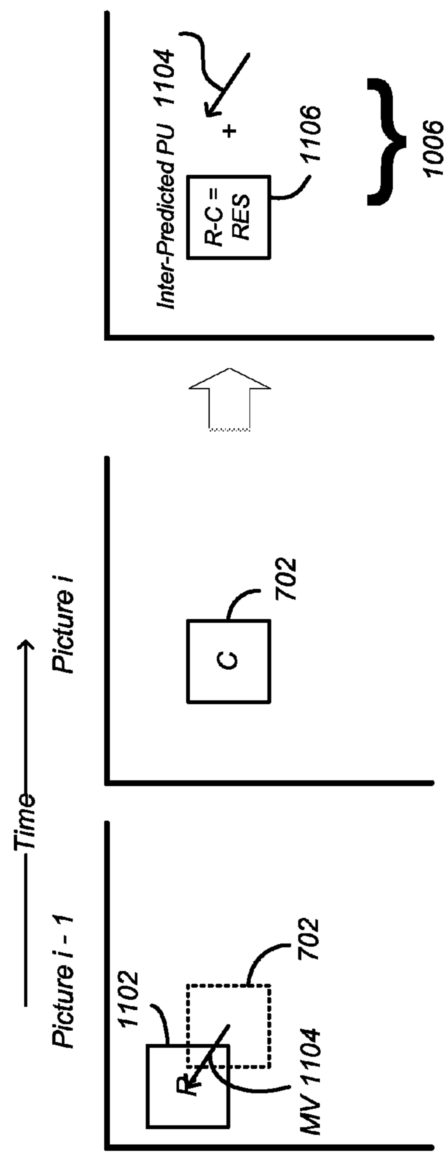

Time
Picture i - 1
1102
R
702
MV 1104
Picture i
C
702
Inter-Predicted PU 1104
R-C =
RES
1106
1006

FIG. 11

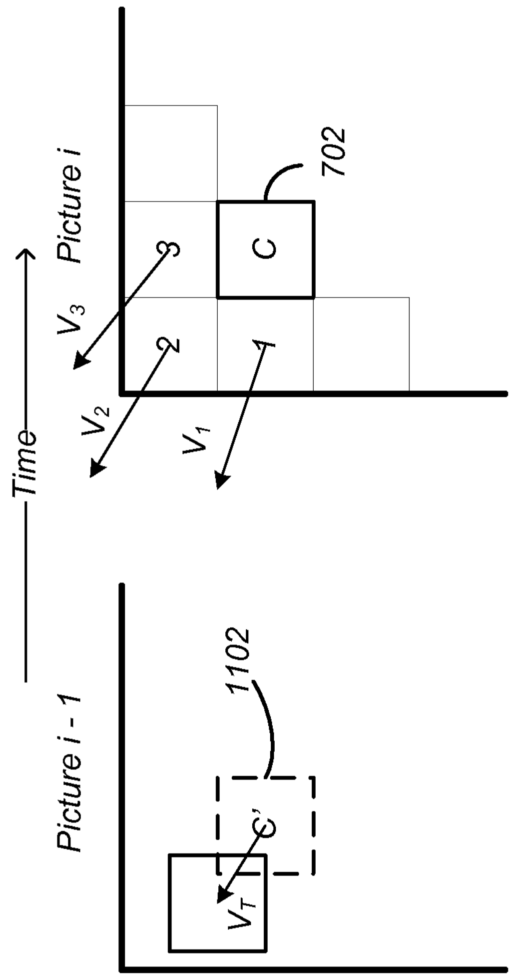


FIG. 12

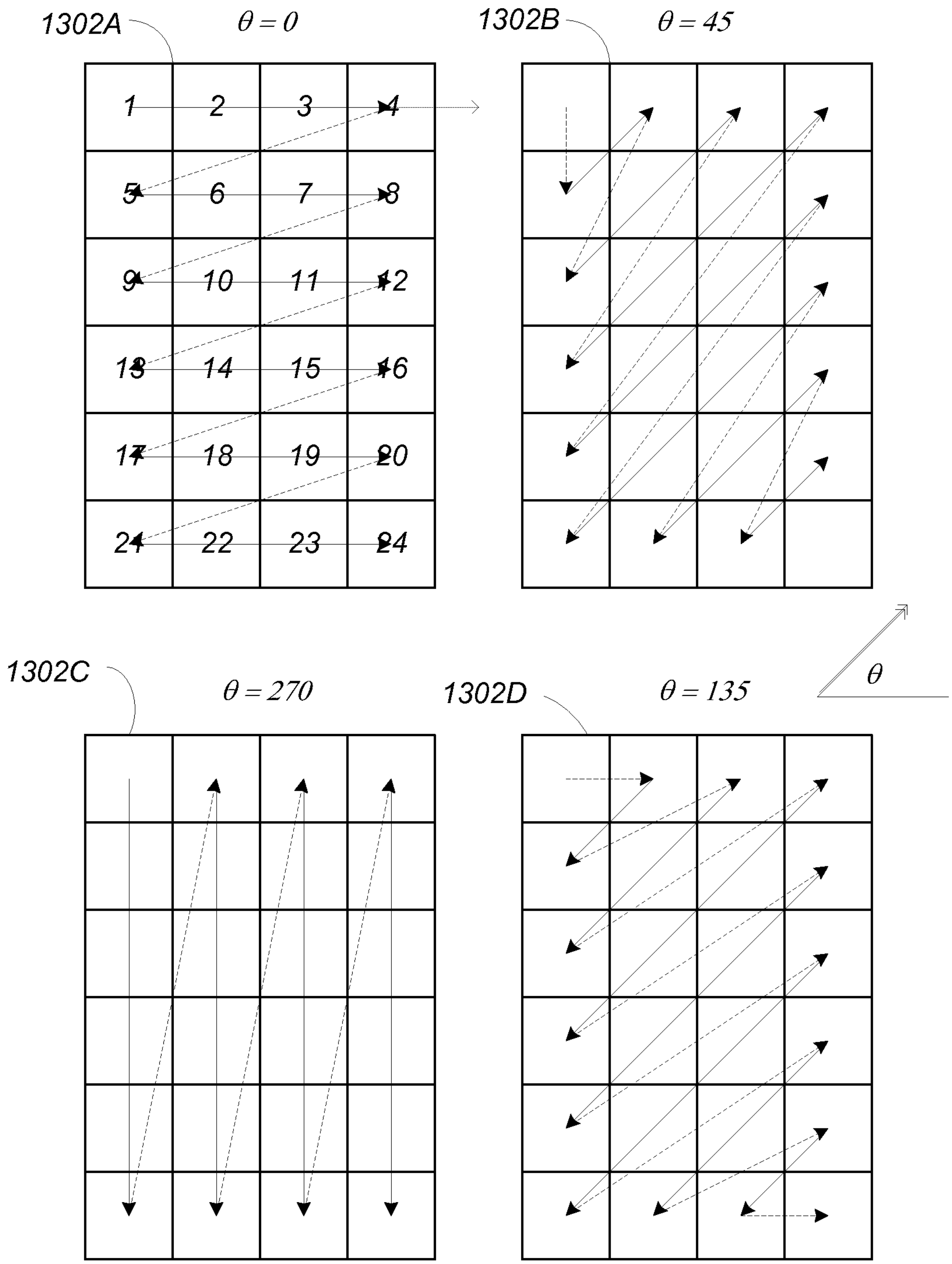

1302A
θ = 0
1 2 3 4
5 6 7 8
9 10 11 12
13 14 15 16
17 18 19 20
21 22 23 24
1302B
θ = 45
θ
1302C
θ = 270
1302D
θ = 135

FIG. 13

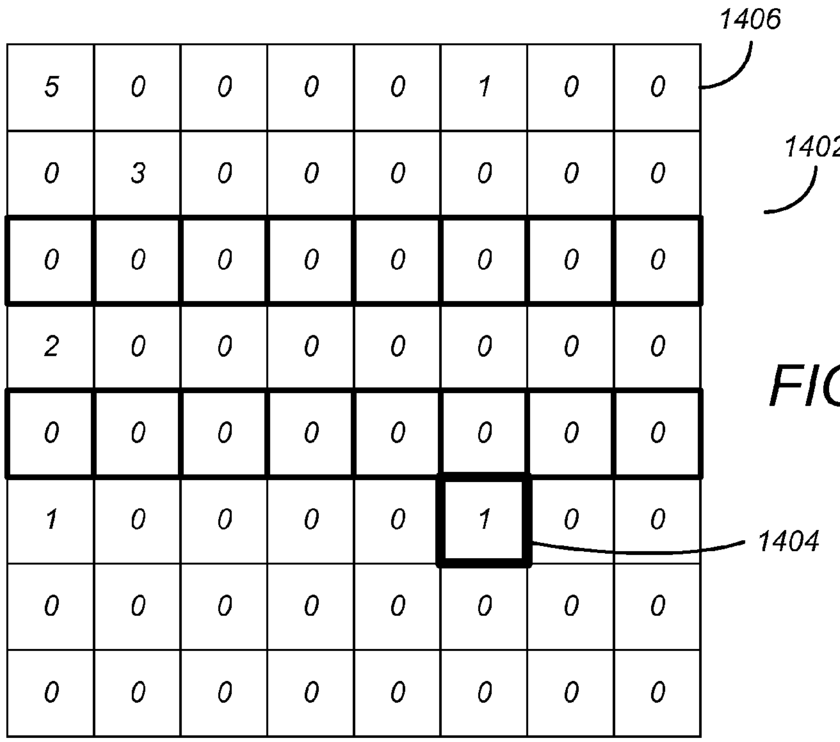


FIG. 14A

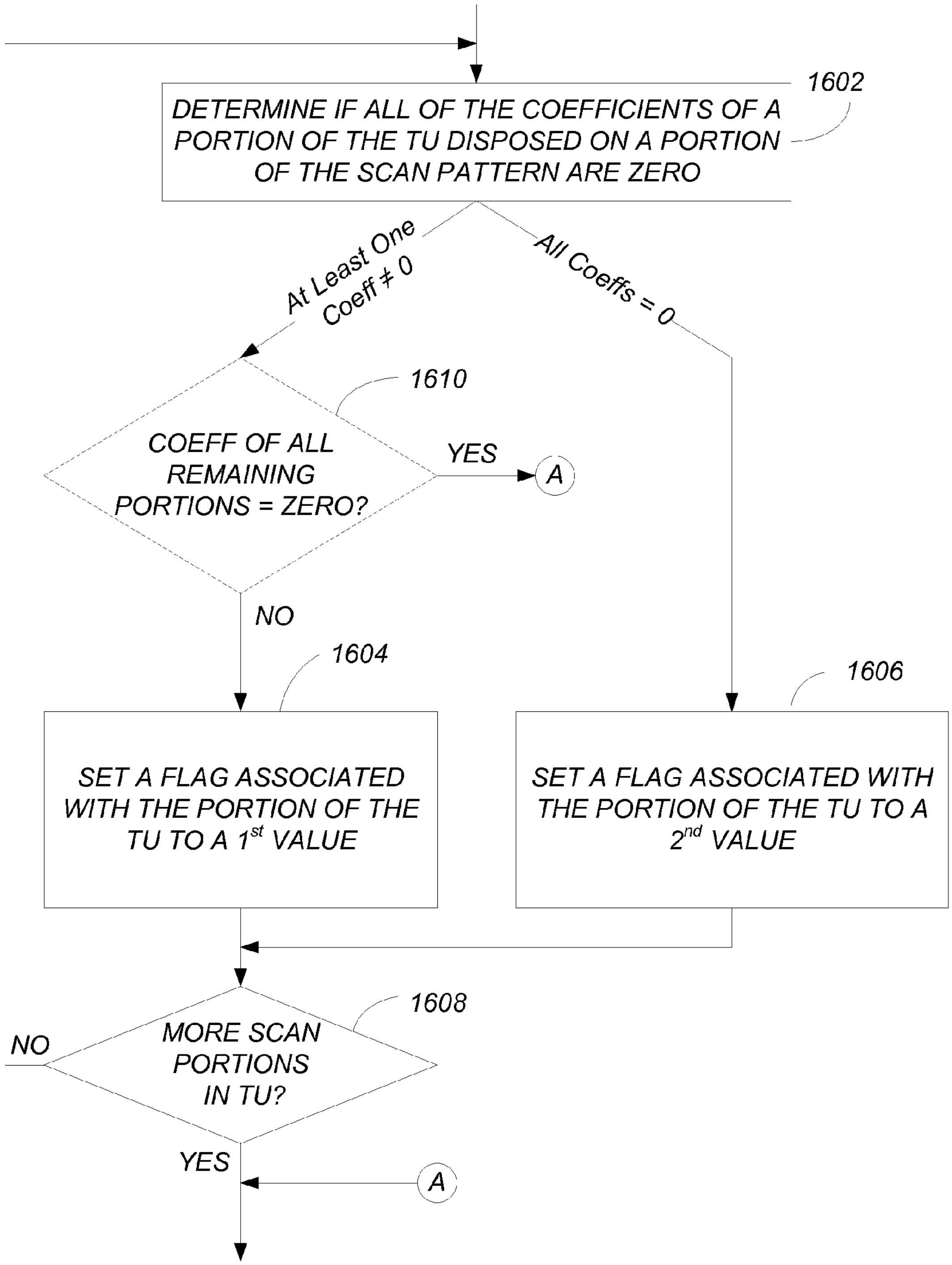
FIG. 14B

Initialisation variables	last_significant_coefficient_x and last_significant_coeff_y ctxIdx														
	0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
m	14	10	12	22	10	9	17	15	16	17	18	16	23	20	24
n	25	38	41	25	37	40	19	21	18	16	13	18	-2	-2	-9
	15	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**
m	24	18	9	22	37	35	53	31	13	21	35	22	18	9	14
n	-7	10	24	-7	9	14	-5	21	39	28	2	17	23	40	32
	30	**31**	**32**	**33**	**34**	**35**	**36**	**37**	**38**	**39**	**40**	**41**	**42**	**43**	**44**
m	7	12	12	13	21	24	23	13	22	29	29	27	20	25	30
n	44	35	40	47	16	10	15	34	10	10	-8	-5	7	13	-8
	45	**46**	**47**	**48**	**49**	**50**	**51**	**52**	**53**	**54**	**55**	**56**	**57**	**58**	**59**
m	35	37	42	42	43	21	22	35	11	22	27	-3	14	23	27
n	-20	-29	-41	-45	-46	36	37	27	53	27	18	83	35	18	3
	60	**61**	**62**	**63**	**64**	**65**	**66**	**67**	**68**	**69**	**70**	**71**	**72**	**73**	**74**
m	32	17	12	12	13	21	24	23	13	22	29	29	27	20	25
n	-11	11	35	40	47	16	10	15	34	10	10	-8	-5	7	13
	75	**76**	**77**	**78**	**79**	**80**	**81**	**82**	**83**	**84**	**85**	**86**	**87**	**88**	**89**
m	30	35	37	42	42	43	21	22	35	11	22	27	-3	14	23
n	-8	-20	-29	-41	-45	-46	36	37	27	53	27	18	83	35	18
	90	**91**	**92**	**93**	**94**	**95**	**96**	**97**	**98**	**99**	**100**	**101**	**102**	**103**	**104**
m	27	32	17												
n	3	-11	11												

FIG. 15A

	Type	*MaxBinIdxCtx*	*ctxIdxOffset*
last_significant_coeff_x *last_significant_coeff_y*	I	30	0
	P	30	31
	B	30	62

FIG. 15B



1602
DETERMINE IF ALL OF THE COEFFICIENTS OF A PORTION OF THE TU DISPOSED ON A PORTION OF THE SCAN PATTERN ARE ZERO
At Least One Coeff ≠ 0
All Coeffs = 0
1610
COEFF OF ALL REMAINING PORTIONS = ZERO?
YES
A
NO
1604
SET A FLAG ASSOCIATED WITH THE PORTION OF THE TU TO A 1st VALUE
1606
SET A FLAG ASSOCIATED WITH THE PORTION OF THE TU TO A 2nd VALUE
1608
MORE SCAN PORTIONS IN TU?
NO
YES
A

FIG. 16A

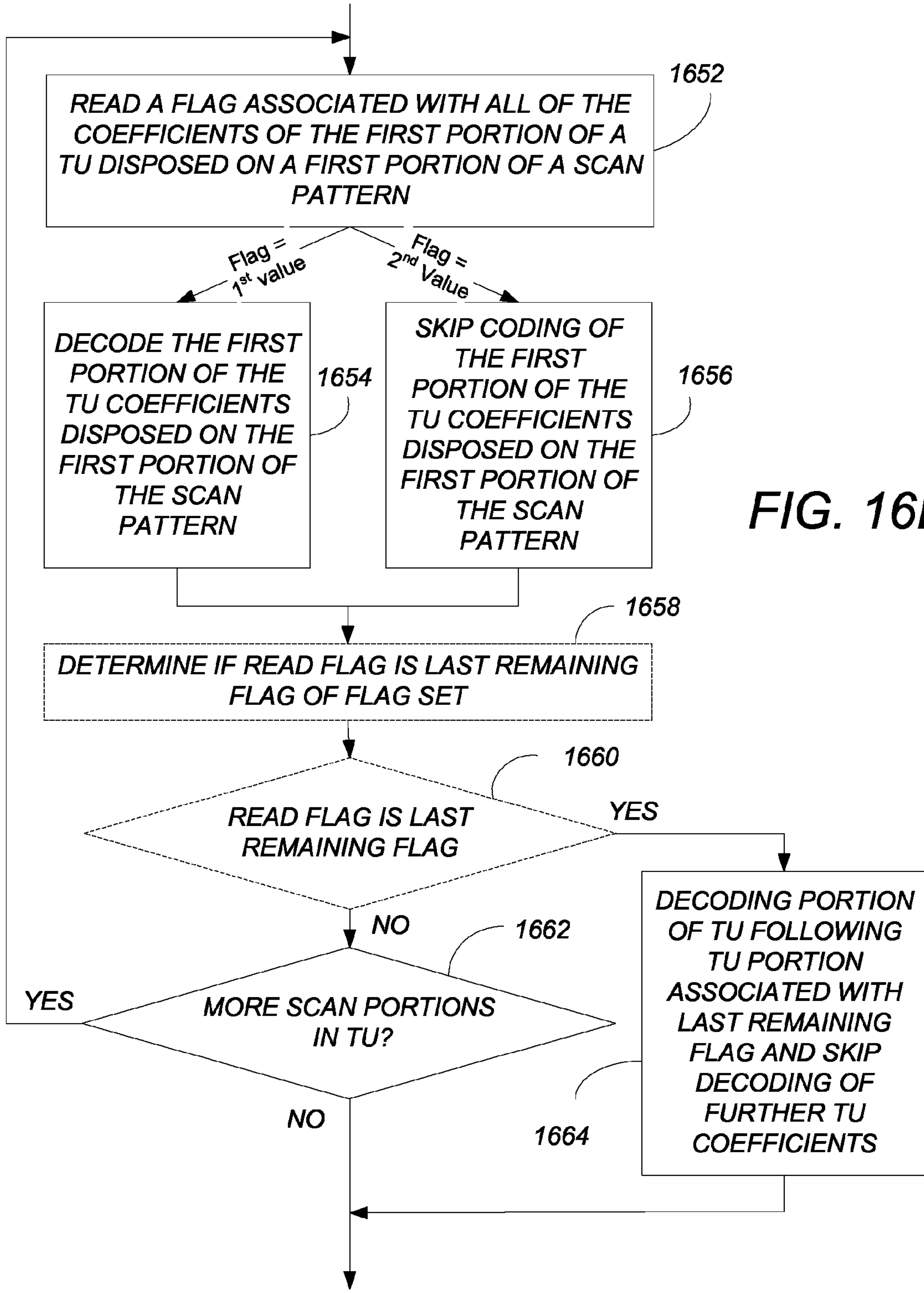

1652
READ A FLAG ASSOCIATED WITH ALL OF THE COEFFICIENTS OF THE FIRST PORTION OF A TU DISPOSED ON A FIRST PORTION OF A SCAN PATTERN
Flag = 1st value
Flag = 2nd Value
DECODE THE FIRST PORTION OF THE TU COEFFICIENTS DISPOSED ON THE FIRST PORTION OF THE SCAN PATTERN
1654
SKIP CODING OF THE FIRST PORTION OF THE TU COEFFICIENTS DISPOSED ON THE FIRST PORTION OF THE SCAN PATTERN
1656
1658
DETERMINE IF READ FLAG IS LAST REMAINING FLAG OF FLAG SET
1660
READ FLAG IS LAST REMAINING FLAG
YES
NO
1662
MORE SCAN PORTIONS IN TU?
YES
NO
DECODING PORTION OF TU FOLLOWING TU PORTION ASSOCIATED WITH LAST REMAINING FLAG AND SKIP DECODING OF FURTHER TU COEFFICIENTS
1664

FIG. 16B

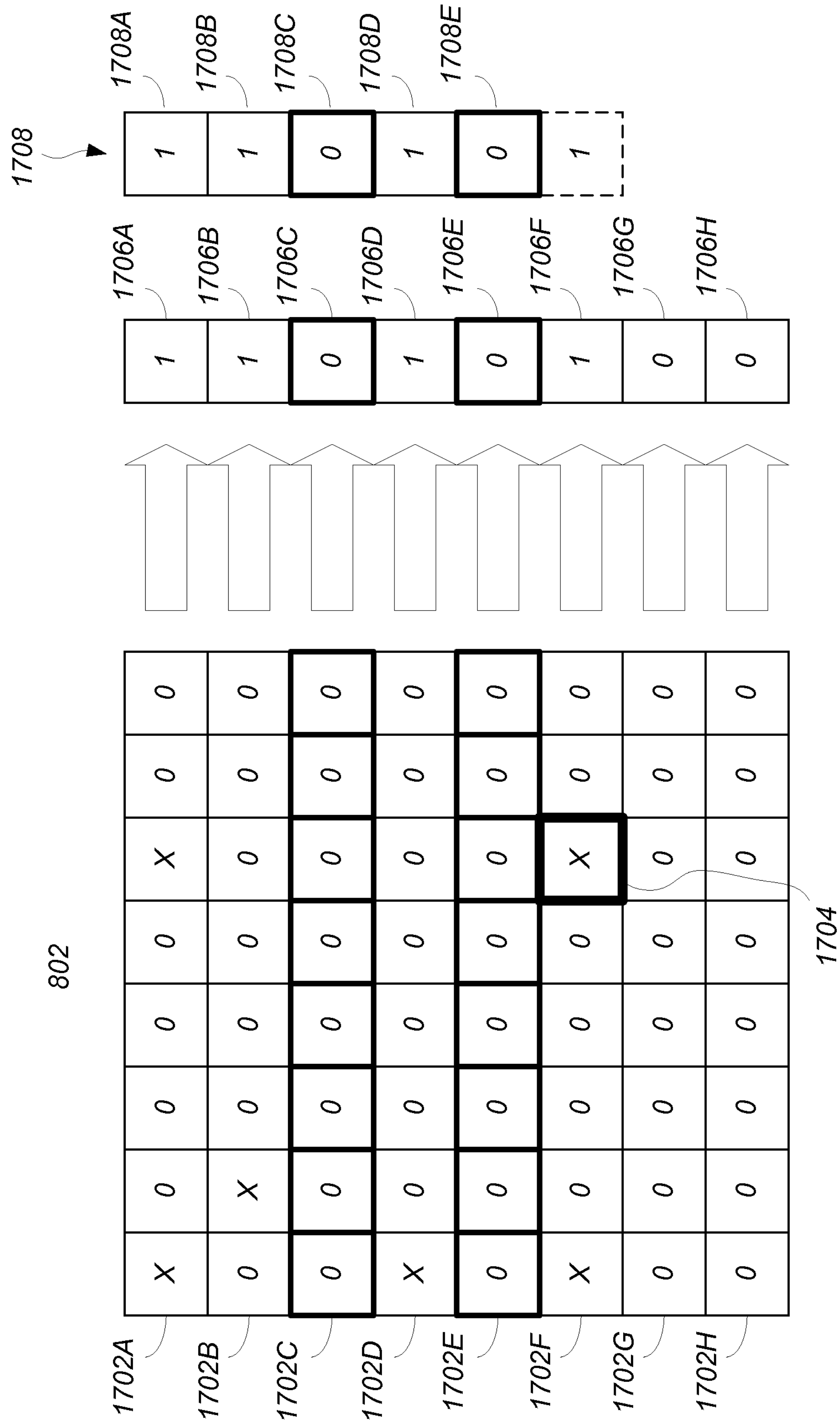

1708
1708A
1708B
1708C
1708D
1708E
1706A
1706B
1706C
1706D
1706E
1706F
1706G
1706H
802
1704
1702A
1702B
1702C
1702D
1702E
1702F
1702G
1702H

FIG. 17

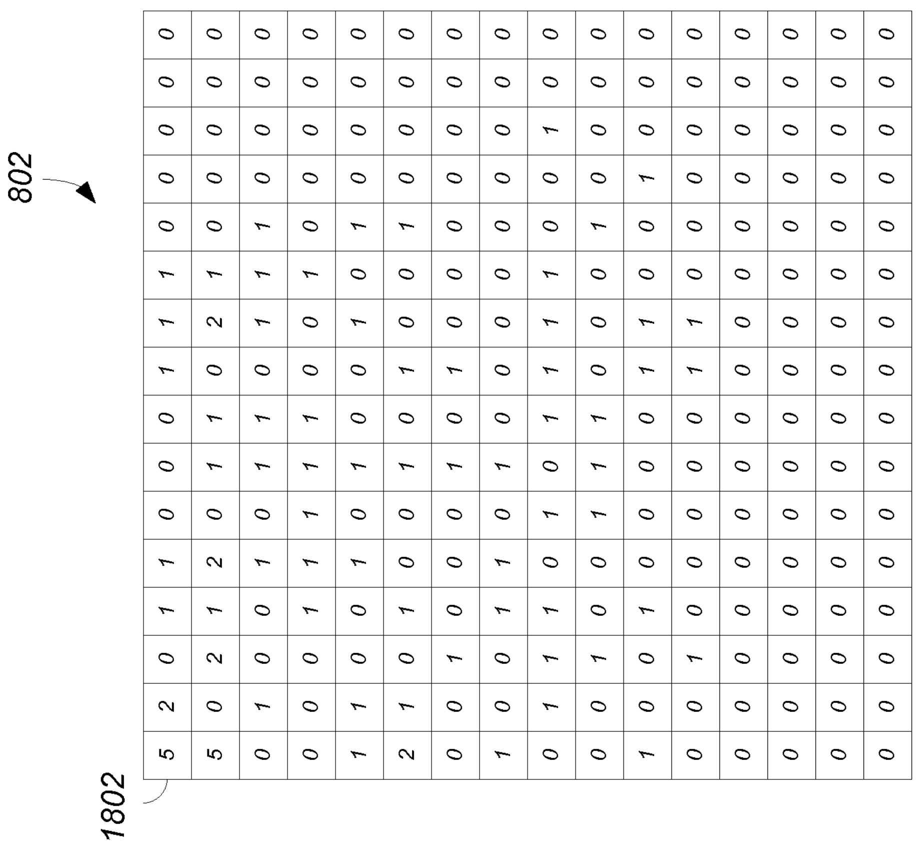


FIG. 18A

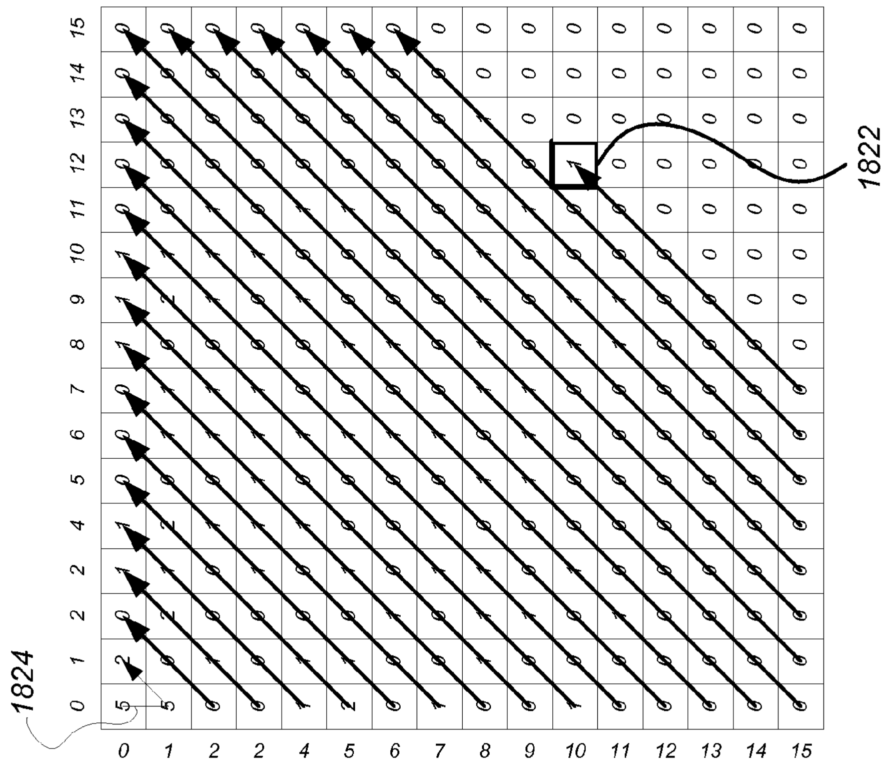


FIG. 18C

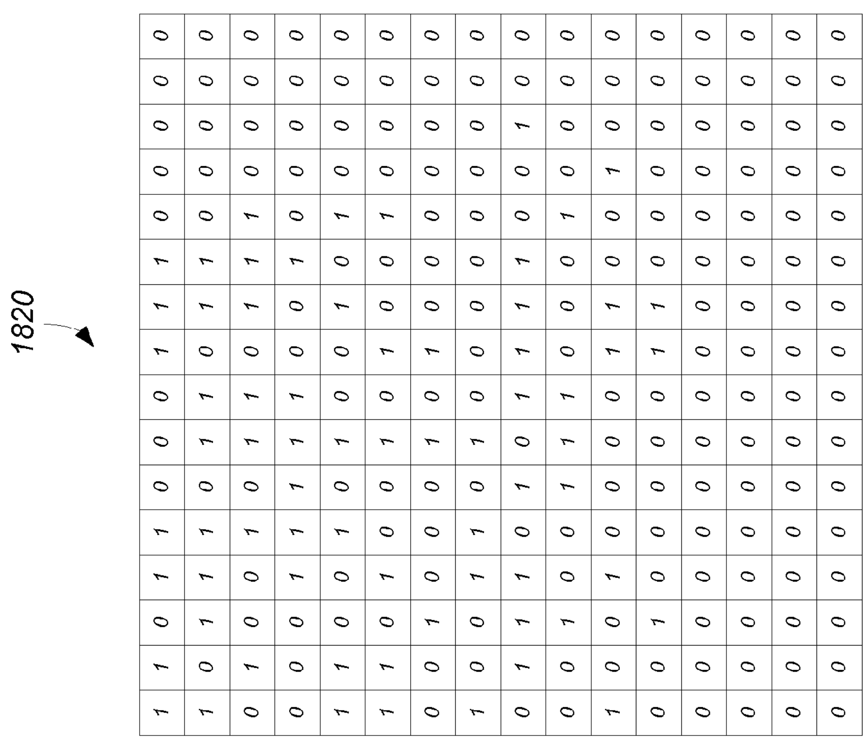


FIG. 18B

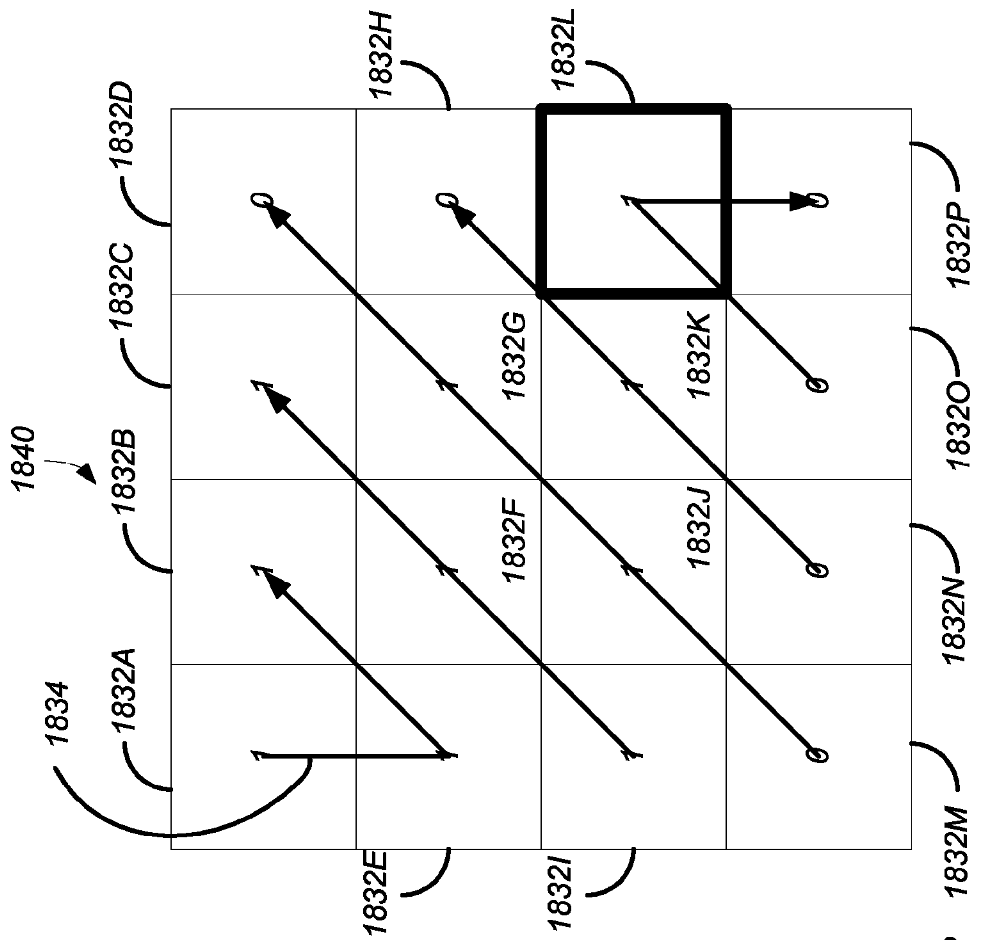


FIG. 18E

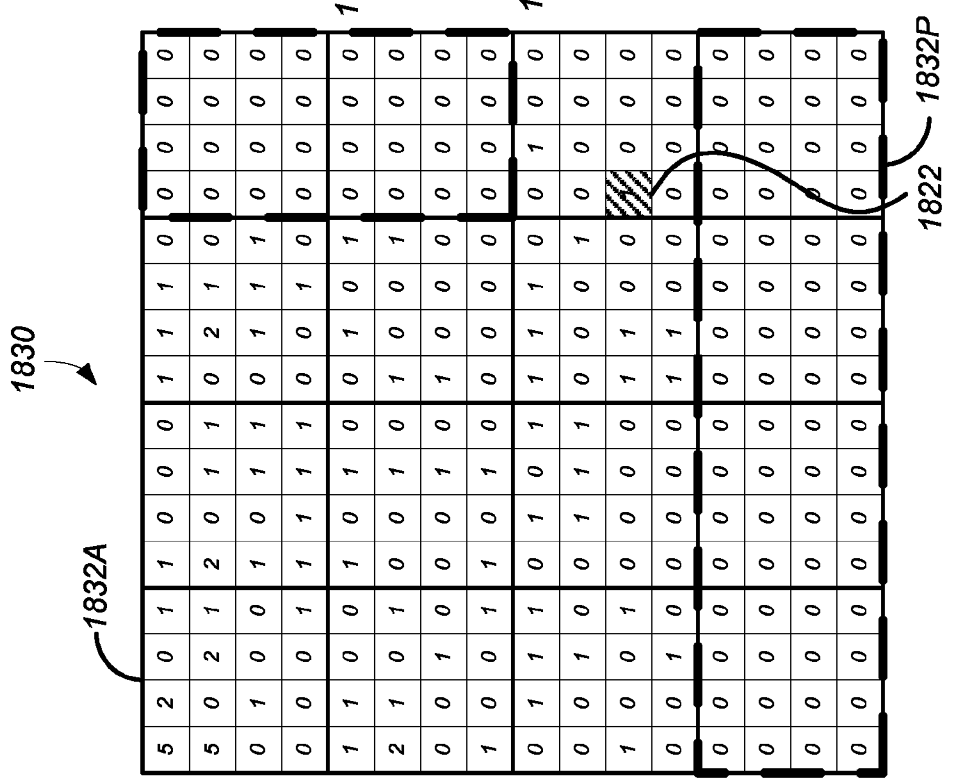


FIG. 18D

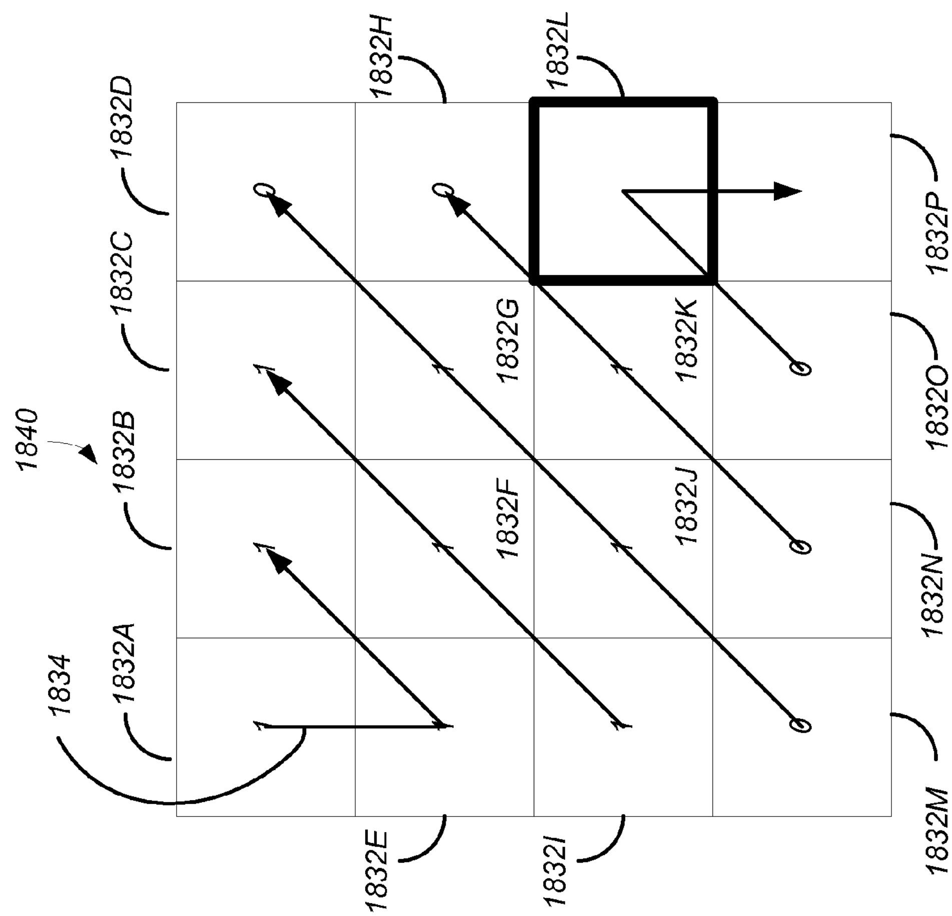

1840
1834
1832A
1832B
1832C
1832D
1832E
1832F
1832G
1832H
1832I
1832J
1832K
1832L
1832M
1832N
1832O
1832P

FIG. 18F

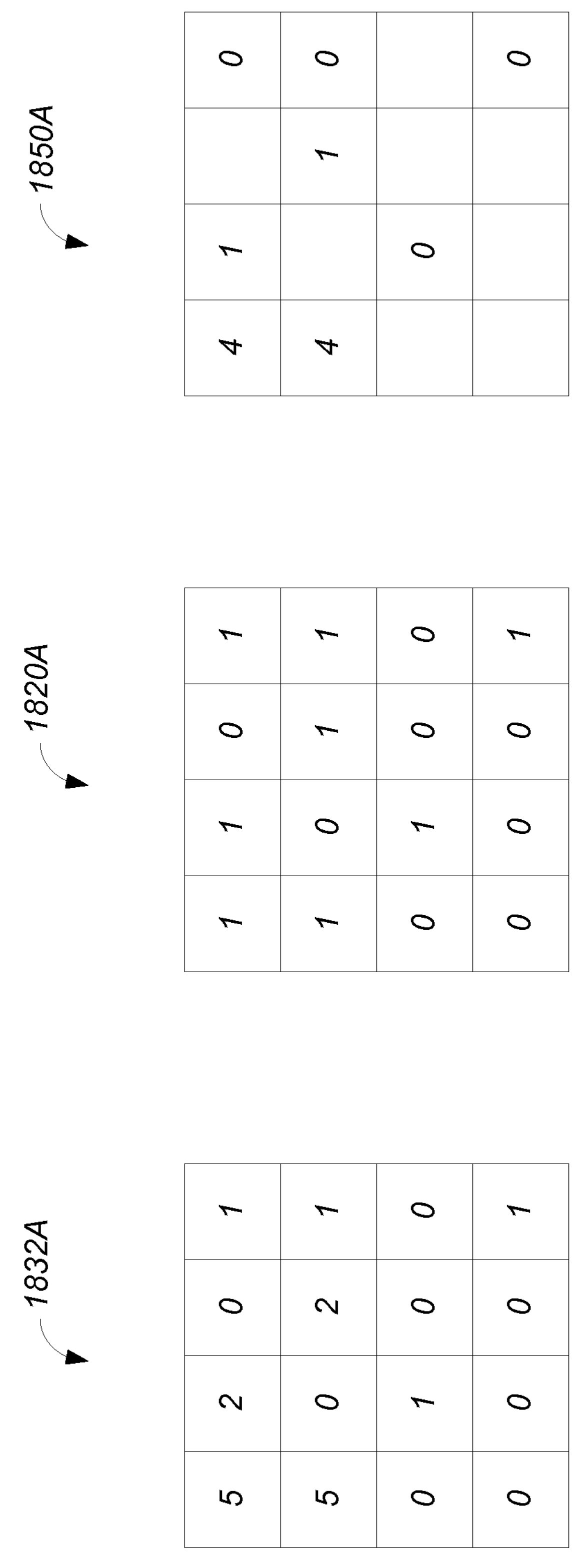


FIG. 18G

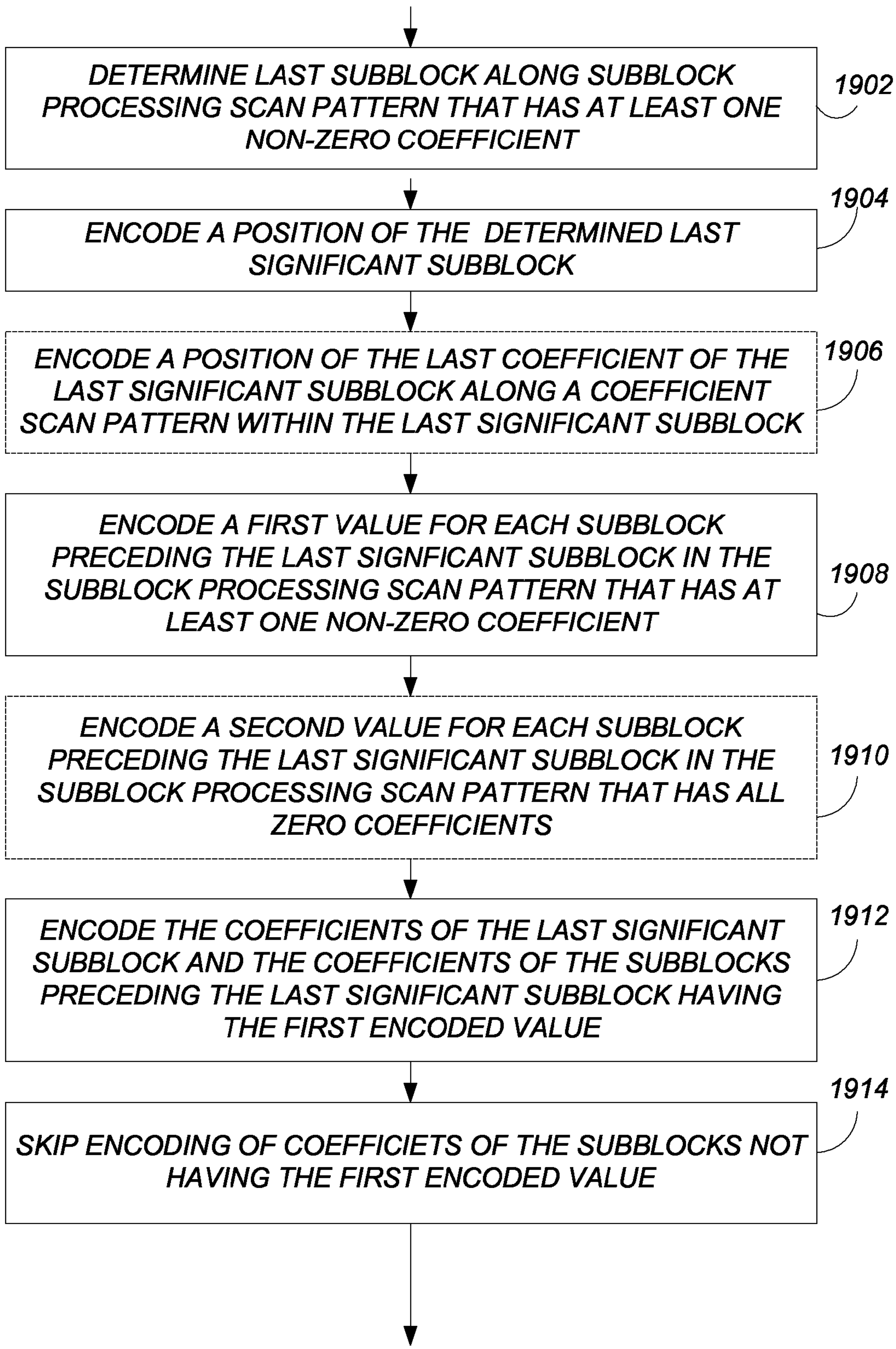

DETERMINE LAST SUBBLOCK ALONG SUBBLOCK PROCESSING SCAN PATTERN THAT HAS AT LEAST ONE NON-ZERO COEFFICIENT
1902
ENCODE A POSITION OF THE DETERMINED LAST SIGNIFICANT SUBBLOCK
1904
ENCODE A POSITION OF THE LAST COEFFICIENT OF THE LAST SIGNIFICANT SUBBLOCK ALONG A COEFFICIENT SCAN PATTERN WITHIN THE LAST SIGNIFICANT SUBBLOCK
1906
ENCODE A FIRST VALUE FOR EACH SUBBLOCK PRECEDING THE LAST SIGNFICANT SUBBLOCK IN THE SUBBLOCK PROCESSING SCAN PATTERN THAT HAS AT LEAST ONE NON-ZERO COEFFICIENT
1908
ENCODE A SECOND VALUE FOR EACH SUBBLOCK PRECEDING THE LAST SIGNIFICANT SUBBLOCK IN THE SUBBLOCK PROCESSING SCAN PATTERN THAT HAS ALL ZERO COEFFICIENTS
1910
ENCODE THE COEFFICIENTS OF THE LAST SIGNIFICANT SUBBLOCK AND THE COEFFICIENTS OF THE SUBBLOCKS PRECEDING THE LAST SIGNIFICANT SUBBLOCK HAVING THE FIRST ENCODED VALUE
1912
SKIP ENCODING OF COEFFICIETS OF THE SUBBLOCKS NOT HAVING THE FIRST ENCODED VALUE
1914

FIG. 19

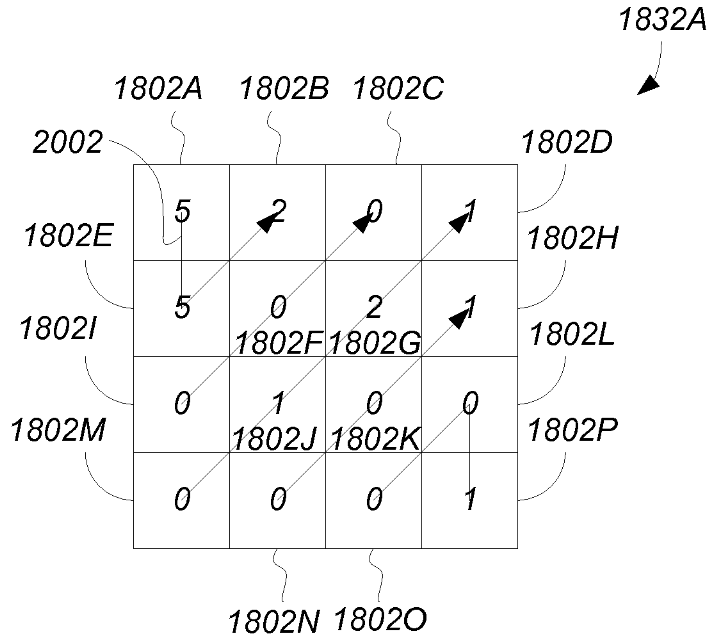

1832A
1802A
1802B
1802C
1802D
2002
1802E
1802H
1802I
1802L
1802M
1802P
1802F
1802G
1802J
1802K
1802N
1802O
5 2 0 1
5 0 2 1
0 1 0 0
0 0 0 1

FIG. 20

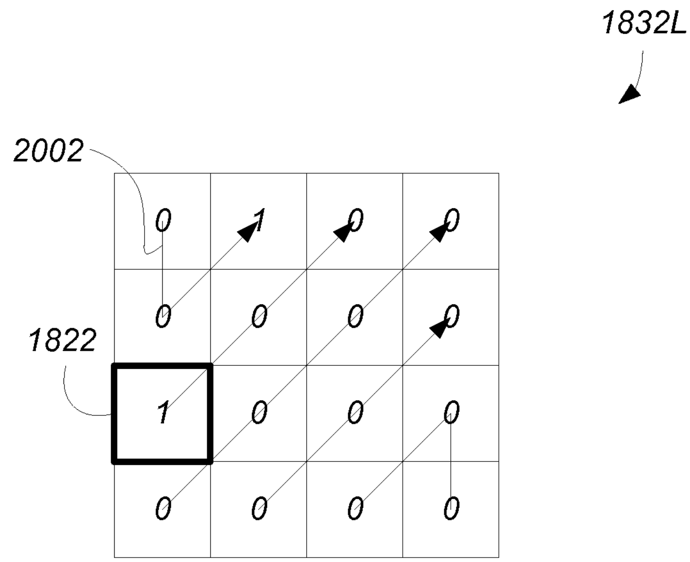

1832L
2002
1822
0 1 0 0
0 0 0 0
1 0 0 0
0 0 0 0

FIG. 21

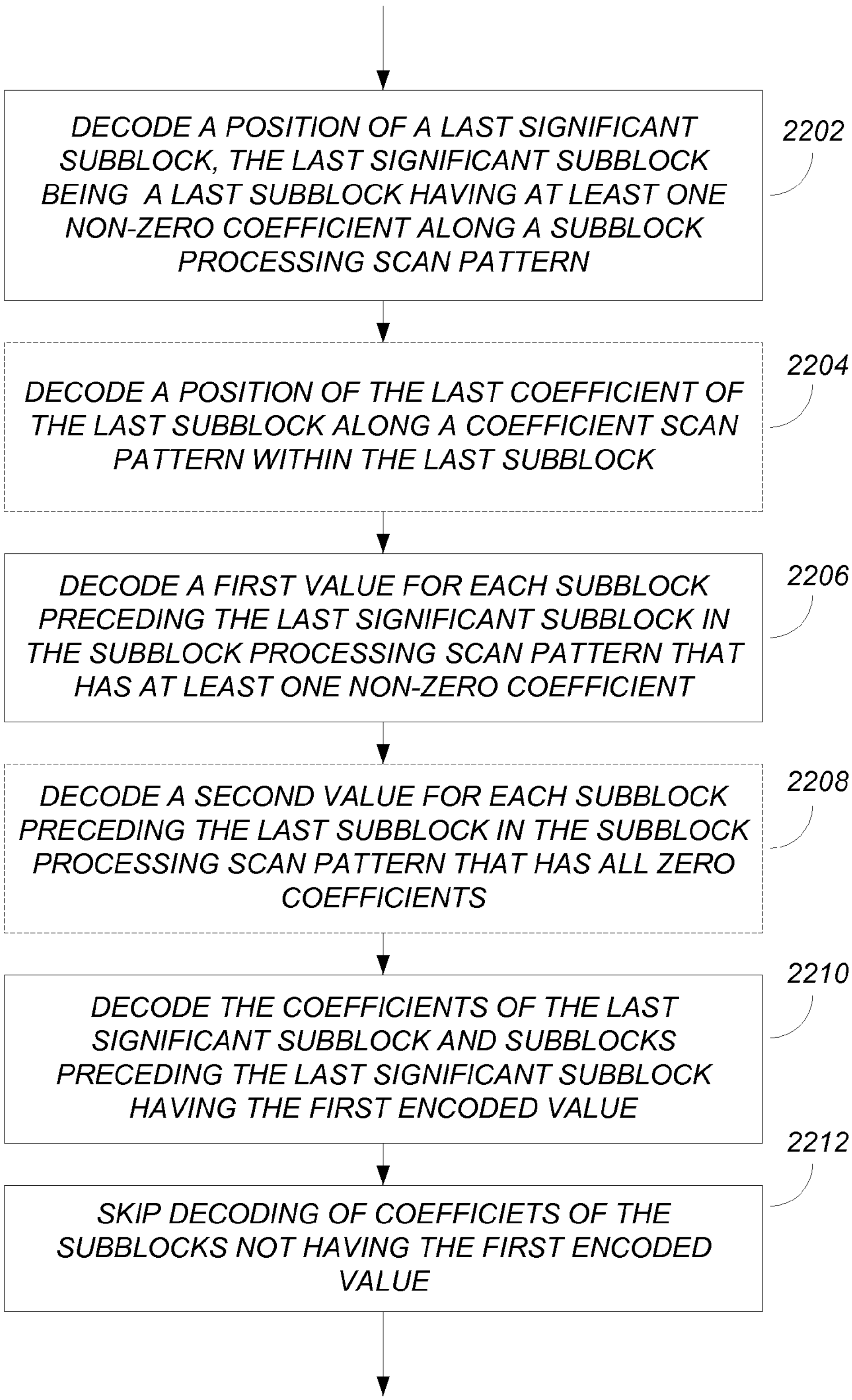

DECODE A POSITION OF A LAST SIGNIFICANT SUBBLOCK, THE LAST SIGNIFICANT SUBBLOCK BEING A LAST SUBBLOCK HAVING AT LEAST ONE NON-ZERO COEFFICIENT ALONG A SUBBLOCK PROCESSING SCAN PATTERN
2202
DECODE A POSITION OF THE LAST COEFFICIENT OF THE LAST SUBBLOCK ALONG A COEFFICIENT SCAN PATTERN WITHIN THE LAST SUBBLOCK
2204
DECODE A FIRST VALUE FOR EACH SUBBLOCK PRECEDING THE LAST SIGNIFICANT SUBBLOCK IN THE SUBBLOCK PROCESSING SCAN PATTERN THAT HAS AT LEAST ONE NON-ZERO COEFFICIENT
2206
DECODE A SECOND VALUE FOR EACH SUBBLOCK PRECEDING THE LAST SUBBLOCK IN THE SUBBLOCK PROCESSING SCAN PATTERN THAT HAS ALL ZERO COEFFICIENTS
2208
DECODE THE COEFFICIENTS OF THE LAST SIGNIFICANT SUBBLOCK AND SUBBLOCKS PRECEDING THE LAST SIGNIFICANT SUBBLOCK HAVING THE FIRST ENCODED VALUE
2210
SKIP DECODING OF COEFFICIETS OF THE SUBBLOCKS NOT HAVING THE FIRST ENCODED VALUE
2212

FIG. 22

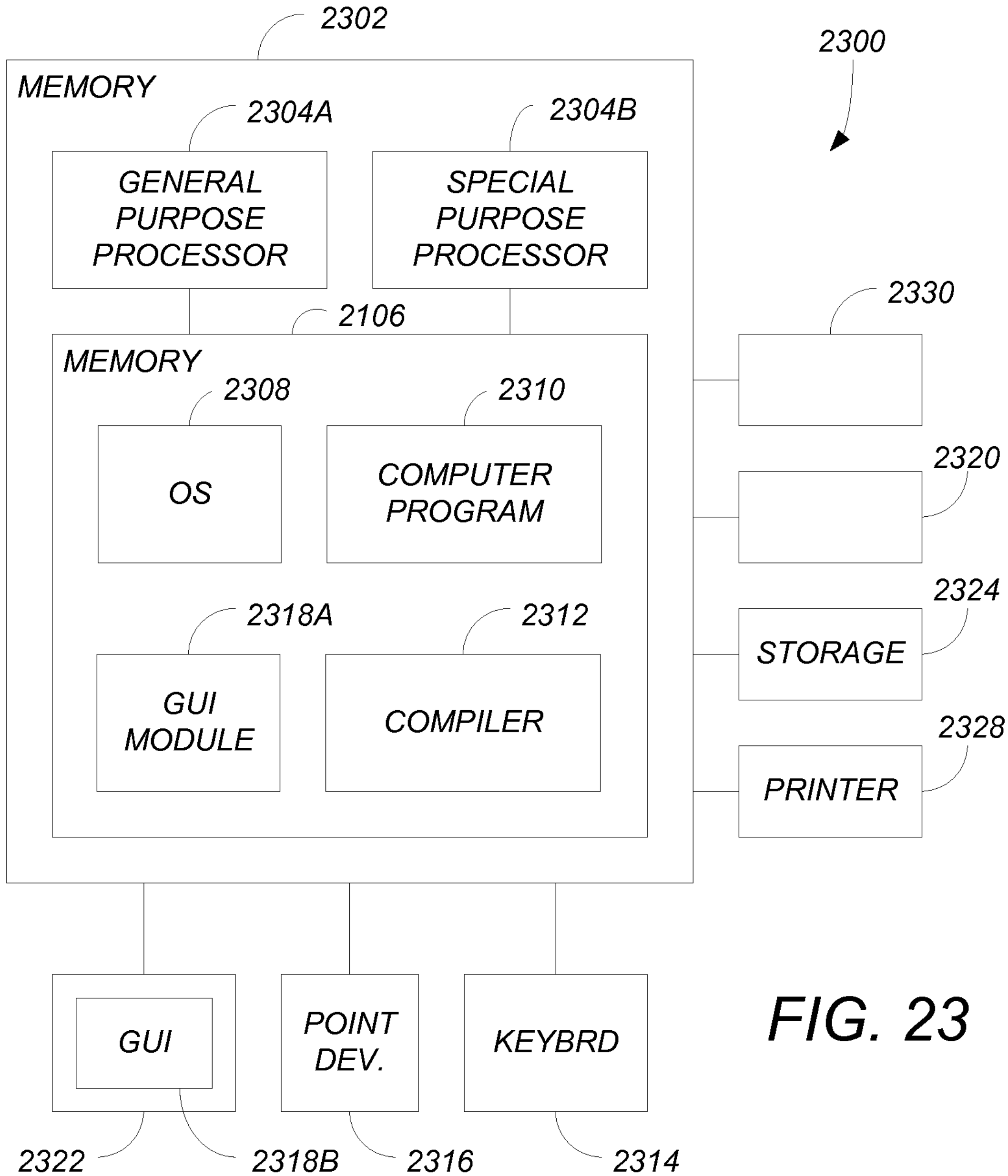

2302
2300
MEMORY
2304A
2304B
GENERAL PURPOSE PROCESSOR
SPECIAL PURPOSE PROCESSOR
2330
2106
MEMORY
2308
2310
OS
COMPUTER PROGRAM
2320
2318A
2312
2324
STORAGE
GUI MODULE
COMPILER
2328
PRINTER
GUI
POINT DEV.
KEYBRD
2322
2318B
2316
2314

FIG. 23

METHOD AND APPARATUS FOR LAST COEFFICIENT INDEXING FOR HIGH EFFICIENCY VIDEO CODING

CROSS-REFERENCE TO RELATED APPLICATIONS

This application claims benefit of U.S. Provisional Patent Application No. 61/577,898, entitled "LAST COEFFICIENT GROUP POSITION CODING IN HEVC," by Xue Fang, Krit Panusopone, and Limin Wang, filed Dec. 20, 2011, which application is also hereby incorporated by reference herein.

This application is related to U.S. Utility patent application Ser. No. 13/722,702, entitled "METHOD AND APPARATUS FOR LAST COEFFICIENT GROUP POSITION CODING," by Xue Fang, Krit Panusopone, and Limin Wang, filed on Dec. 20, 2012 which is hereby incorporated by reference herein.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to systems and methods for encoding data, and in particular to a system and method for storing motion and retrieving data associated with high efficiency video coded data.

2. Description of the Related Art

There is rapid growth in the technologies associated with the generation, transmission, and reproduction of media programs. These technologies include coding schemes that permit digital versions of the media programs to be encoded to compress them to much smaller size and facilitate their transmission, storage, reception and playback. These technologies have application in personal video recorders (PVRs), video on demand (VOD), multiple channel media program offerings, interactivity, mobile telephony, and media program transmission.

Without compression, digital media programs are typically too large to transmit and/or store for a commercially acceptable cost. However, compression of such programs has made the transmission and storage of such digital media programs not only commercially feasible, but commonplace.

Initially, the transmission of media programs involved low to medium resolution images transmitted over high bandwidth transmission media such as cable television and satellite. However, such transmission has evolved to include lower bandwidth transmission media such as Internet transmission to fixed and mobile devices via computer networks, WiFi, Mobile TV and third and fourth generation (3G and 4G) networks. Further, such transmissions have also evolved to include high definition media programs such as high definition television (HDTV), which have significant transmission bandwidth and storage requirements.

The encoding and decoding of compressed video signals typically involves the storage and retrieval of large volumes of data by both the encoder of the signals and the decoder of the signals. As a consequence, such encoders and decoders require increased storage and processing capacity. What is needed is a system and method that reduces the storage and processing required in the encoder and decoder. The present invention satisfies this need.

SUMMARY OF THE INVENTION

To address the requirements described above, this document discloses a method, apparatus, article of manufacture,

and a memory structure for processing a transform unit having an array of coefficients is disclosed. One embodiment is evidenced by a method comprising determining if all of the coefficients of a portion of the transform unit disposed on a portion of a scan pattern are zero, setting a flag associated with the portion of the transform unit to a first value if at least one of the coefficients of the portion of the transform unit coefficients disposed on the portion of the scan pattern are non-zero, and setting the flag associated with the portion of the transform unit coefficients to a second value if all of the coefficients of the portion of the transform unit coefficients disposed in the portion of the scan pattern are zero.

Another embodiment is manifested by an apparatus comprising a processor and a memory coupled to the processor, storing instructions for performing steps comprising the operations listed above.

The features, functions, and advantages that have been discussed can be achieved independently in various embodiments of the present invention or may be combined in yet other embodiments further details of which can be seen with reference to the following description and drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

Referring now to the drawings in which like reference numbers represent corresponding parts throughout:

FIG. **1** is a diagram depicting an exemplary embodiment of a video coding-decoding system that can be used for transmission and/or storage and retrieval of audio and/or video information;

FIG. **2**A is a diagram of one embodiment of a codec system **200**A in which the encoded AV information is transmitted to and received at another location;

FIG. **2**B is a diagram depicting an exemplary embodiment of codec system in which the encoded information is stored and later retrieved for presentation, hereinafter referred to as codec storage system;

FIG. **2**C is a diagram depicting an exemplary content distribution system comprising an encoder and a decoder that can be used to transmit and receive HEVC data;

FIG. **3** is a block diagram illustrating one embodiment of the source encoder;

FIG. **4** is a diagram depicting a picture of AV information, such as one of the pictures in the picture sequence;

FIG. **5** is a diagram showing an exemplary partition of a coding tree block into coding units;

FIG. **6** is a diagram illustrating a representation of a representative quadtree and data parameters for the code tree block partitioning shown in FIG. **5**;

FIG. **7** is a diagram illustrating the partition of a coding unit into one or more prediction units;

FIG. **8** is a diagram showing a coding unit partitioned into four prediction units and an associated set of transform units;

FIG. **9** is a diagram showing RQT codetree for the transform units associated with the coding unit in the example of FIG. **8**;

FIG. **10** is a diagram illustrating spatial prediction of prediction units;

FIG. **11** is a diagram illustrating temporal prediction;

FIG. **12** is a diagram illustrating the use of motion vector predictors (MVPs);

FIG. **13** is a diagram illustrating exemplary scan patterns used for coding of the quantized coefficients of a non-square transform unit;

FIG. **14**A is an diagram of an exemplary transform unit coefficient map;

FIG. **14**B is a diagram of an exemplary significance map of the transform unit of FIG. **14**A;

FIG. **15**A presents a table for determining the initialization variables in an entropy encoder;

FIG. **15**B presents a table showing the an offset for different coding unit type;

FIG. **16**A is diagram presenting an exemplary technique for performing a last coefficient coding technique that can be used in an HEVC encoding/decoding system;

FIG. **16**B is a diagram illustrating the decoding of the encoded bitstream, using the last coefficient coding described in FIG. **16**A;

FIG. **17** is a diagram illustrating the operations of FIGS. **16**A and **16**B;

FIG. **18**A is a diagram of 16×16 transform unit;

FIG. **18**B is a significance map generated from the transform unit illustrated in FIG. **18**A;

FIG. **18**C is a diagram illustrating an exemplary array scan pattern and a last significant coefficient of a transform unit;

FIG. **18**D is a diagram illustrating a transform unit that has been partitioned into sixteen non-overlapping subblocks;

FIG. **18**E is a diagram of an L1 significance map corresponding to the partitioned transform unit of FIG. **18**D;

FIG. **18**F is a diagram of an alternative L1 significance map showing encoded subblock values;

FIG. **18**G is a diagram illustrating the coding of the transform coefficients within an exemplary subblock;

FIG. **19** is diagram presenting an exemplary technique for performing a last subblock coding technique that can be used in an HEVC encoding/decoding system;

FIG. **20** presents a diagram illustrating the coefficients of a candidate subblock having the first encoded value indicating that it includes non-zero coefficients;

FIG. **21** is a diagram of the last significant subblock of the transform unit;

FIG. **22** is a diagram illustrating an exemplary technique for decoding transform unit coefficients that were encoded using the foregoing last coefficient group position technique; and

FIG. **23** illustrates an exemplary processing system that can be used to implement the embodiments of the invention.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

In the following description, reference is made to the accompanying drawings which form a part hereof, and which is shown, by way of illustration, several embodiments of the present invention. It is understood that other embodiments may be utilized and structural changes may be made without departing from the scope of the present invention.

Audio-Visual Information Transception and Storage

FIG. **1** is a diagram depicting an exemplary embodiment of a video coding-decoding (codec) system **100** that can be used for transmission and/or storage and retrieval of audio and/or video information. The codec system **100** comprises an encoding system **104**, which accepts audio-visual (AV) information **102** and processes the AV information **102** to generate encoded (compressed) AV information **106**, and a decoding system **112**, which processes the encoded AV information **106** to produce recovered AV information **114**. Since the encoding and decoding processes are not lossless, the recovered AV information **114** is not identical to the initial AV information **102**, but with judicious selection of the encoding processes and parameters, the differences between the recovered AV information **114** and the unprocessed AV information **102** are acceptable to human perception.

The encoded AV information **106** is typically transmitted or stored and retrieved before decoding and presentation, as performed by transception (transmission and reception) or storage/retrieval system **108**. Transception losses may be significant, but storage/retrieval losses are typically minimal or non-existent, hence, the transcepted AV information **110** provided to the decoding system **112** is typically the same as or substantially the same as the encoded AV information **106**.

FIG. **2**A is a diagram of one embodiment of a codec system **200**A in which the encoded AV information **106** is transmitted to and received at another location. A transmission segment **230** converts an input AV information **102** into a signal appropriate for transmission and transmits the converted signal over the transmission channel **212** to the reception segment **232**. The reception segment **232** receives the transmitted signal, and converts the received signal into the recovered AV information **114** for presentation. As described above, due to coding and transmission losses and errors, the recovered AV information **114** may be of lower quality than the AV information **102** that was provided to the transmission segment **230**. However, error correcting systems may be included to reduce or eliminate such errors. For example, the encoded AV information **106** may be forward error correction (FEC) encoded by adding redundant information, and such redundant information can be used to identify and eliminate errors in the reception segment **230**.

The transmission segment **102** comprises one or more source encoders **202** to encode multiple sources of AV information **102**. The source encoder **202** encodes the AV information **102** primarily for purposes of compression to produce the encoded AV information **106**, and may include, for example a processor and related memory storing instructions implementing a codec such as MPEG-1, MPEG-2, MPEG-4 AVC/H.264, HEVC or similar codec, as described further below.

The codec system **200**A may also include optional elements indicated by the dashed lines in FIG. **2**A. These optional elements include a video multiplex encoder **204**, an encoding controller **208**, and a video demultiplexing decoder **218**. The optional video multiplex encoder **204** multiplexes encoded AV information **106** from an associated plurality of source encoder(s) **202** according to one or more parameters supplied by the optional encoding controller **208**. Such multiplexing is typically accomplished in the time domain and is data packet based.

In one embodiment, the video multiplex encoder **204** comprises a statistical multiplexer, which combines the encoded AV information **106** from a plurality of source encoders **202** so as to minimize the bandwidth required for transmission. This is possible, since the instantaneous bit rate of the coded AV information **106** from each source encoder **202** can vary greatly with time according to the content of the AV information **102**. For example, scenes having a great deal of detail and motion (e.g. sporting events) are typically encoded at higher bitrates than scenes with little motion or detail (e.g. portrait dialog). Since each source encoder **202** may produce information with a high instantaneous bit rate while another source encoder **202** produces information with a low instantaneous bit rate, and since the encoding controller **208** can command the source encoders **202** to encode the AV information **106** according to certain performance parameters that affect the instantaneous bit rate, the signals from each of the source encoders **106** (each having a temporally varying instantaneous bit rate) can be combined together in an optimal way to minimize the instantaneous bit rate of the multiplexed stream **205**.

As described above, the source encoder **202** and the video multiplex coder **204** may optionally be controlled by a coding controller **208** to minimize the instantaneous bit rate of the combined video signal. In one embodiment, this is accomplished using information from a transmission buffer **206** which temporarily stores the coded video signal and can indicate the fullness of the buffer **206**. This allows the coding performed at the source encoder **202** or video multiplex coder **204** to be a function of the storage remaining in the transmission buffer **206**.

The transmission segment **230** also may comprise a transmission encoder **210**, which further encodes the video signal for transmission to the reception segment **232**. Transmission encoding may include for example, the aforementioned FEC coding and/or coding into a multiplexing scheme for the transmission medium of choice. For example, if the transmission is by satellite or terrestrial transmitters, the transmission encoder **114** may encode the signal into a signal constellation before transmission via quadrature amplitude modulation (QAM) or similar modulation technique. Also, if the encoded video signal is to be streamed via an Internet protocol device and the Internet, the transmission encodes the signal according to the appropriate protocol. Further, if the encoded signal is to be transmitted via mobile telephony, the appropriate coding protocol is used, as further described below.

The reception segment **232** comprises a transmission decoder **214** to receive the signal that was coded by the transmission coder **210** using a decoding scheme complementary to the coding scheme used in the transmission encoder **214**. The decoded received signal may be temporarily stored by optional reception buffer **216**, and if the received signal comprises multiple video signals, the received signal is multiplex decoded by video multiplex decoder **218** to extract the video signal of interest from the video signals multiplexed by the video multiplex coder **204**. Finally, the video signal of interest is decoded by source decoder **220** using a decoding scheme or codec complementary to the codec used by the source encoder **202** to encode the AV information **102**.

In one embodiment, the transmitted data comprises a packetized video stream transmitted from a server (representing the transmitting segment **230**) to a client (representing the receiving segment **232**). In this case, the transmission encoder **210** may packetize the data and embed network abstract layer (NAL) units in network packets. NAL units define a data container that has header and coded elements, and may correspond to a video frame or other slice of video data.

The compressed data to be transmitted may packetized and transmitted via transmission channel **212**, which may include a Wide Area Network (WAN) or a Local Area Network (LAN). Such a network may comprise, for example, a wireless network such as Wi-Fi, an Ethernet network, an Internet network or a mixed network composed of several different networks. Such communication may be affected via a communication protocol, for example Real-time Transport Protocol (RTP), User Datagram Protocol (UDP) or any other type of communication protocol. Different packetization methods may be used for each network abstract layer (NAL) unit of the bitstream. In one case, one NAL unit size is smaller than the maximum transport unit (MTU) size corresponding to the largest packet size that can be transmitted over the network without being fragmented. In this case, the NAL unit is embedded into a single network packet. In another case, multiple entire NAL units are included in a single network packet. In a third case, one NAL unit may be too large to be transmitted in a single network packet and is thus split into several fragmented NAL units with each fragmented NAL unit being transmitted in an individual network packet. Fragmented NAL unit are typically sent consecutively for decoding purposes.

The reception segment **232** receives the packetized data and reconstitutes the NAL units from the network packet. For fragmented NAL units, the client concatenates the data from the fragmented NAL units in order to reconstruct the original NAL unit. The client **232** decodes the received and reconstructed data stream and reproduces the video images on a display device and the audio data by a loud speaker.

FIG. **2**B is a diagram depicting an exemplary embodiment of codec system in which the encoded information is stored and later retrieved for presentation, hereinafter referred to as codec storage system **200**B. This embodiment may be used, for example, to locally store information in a digital video recorder (DVR), a flash drive, hard drive, or similar device. In this embodiment, the AV information **102** is source encoded by source encoder **202**, optionally buffered by storage buffer **234** before storage in a storage device **236**. The storage device **236** may store the video signal temporarily or for an extended period of time, and may comprise a hard drive, flash drive, RAM or ROM. The stored AV information is then retrieved, optionally buffered by retrieve buffer **238** and decoded by the source decoder **220**.

FIG. **2**C is another diagram depicting an exemplary content distribution system **200**C comprising a coding system or encoder **202** and a decoding system or decoder **220** that can be used to transmit and receive HEVC data. In some embodiments, the coding system **202** can comprise an input interface **256**, a controller **241** a counter **242** a frame memory **243**, an encoding unit **244**, a transmitter buffer **267** and an output interface **257**. The decoding system **220** can comprise a receiver buffer **259**, a decoding unit **260**, a frame memory **261** and a controller **267**. The coding system **202** and the decoding system **220** can be coupled with each other via a transmission path which can carry a compressed bit stream. The controller **241** of the coding system **202** can control the amount of data to be transmitted on the basis of the capacity of the transmitter buffer **267** or receiver buffer **259** and can include other parameters such as the amount of data per a unit of time. The controller **241** can control the encoding unit **244** to prevent the occurrence of a failure of a received signal decoding operation of the decoding system **220**. The controller **241** can be a processor or include, by way of a non-limiting example, a microcomputer having a processor, a random access memory and a read only memory.

Source pictures **246** supplied from, by way of a non-limiting example, a content provider can include a video sequence of frames including source pictures in a video sequence. The source pictures **246** can be uncompressed or compressed. If the source pictures **246** are uncompressed, the coding system **202** can have an encoding function. If the source pictures **246** are compressed, the coding system **202** can have a transcoding function. Coding units can be derived from the source pictures utilizing the controller **241**. The frame memory **243** can have a first area that can be used for storing the incoming frames from the source pictures **246** and a second area that can be used for reading out the frames and outputting them to the encoding unit **244**. The controller **241** can output an area switching control signal **249** to the frame memory **243**. The area switching control signal **249** can indicate whether the first area or the second area is to be utilized.

The controller **241** can output an encoding control signal **250** to the encoding unit **244**. The encoding control signal **250** can cause the encoding unit **202** to start an encoding operation, such as preparing the Coding Units based on a source picture. In response to the encoding control signal **250** from the controller **241**, the encoding unit **244** can begin to read out the prepared Coding Units to a high-efficiency encoding process, such as a prediction coding process or a transform coding process which process the prepared Coding Units generating video compression data based on the source pictures associated with the Coding Units.

The encoding unit **244** can package the generated video compression data in a packetized elementary stream (PES) including video packets. The encoding unit **244** can map the video packets into an encoded video signal **248** using control information and a program time stamp (PTS) and the encoded video signal **248** can be transmitted to the transmitter buffer **267**.

The encoded video signal **248**, including the generated video compression data, can be stored in the transmitter buffer **267**. The information amount counter **242** can be incremented to indicate the total amount of data in the transmitter buffer **267**. As data is retrieved and removed from the buffer, the counter **242** can be decremented to reflect the amount of data in the transmitter buffer **267**. The occupied area information signal **253** can be transmitted to the counter **242** to indicate whether data from the encoding unit **244** has been added or removed from the transmitter buffer **267** so the counter **242** can be incremented or decremented. The controller **241** can control the production of video packets produced by the encoding unit **244** on the basis of the occupied area information **253** which can be communicated in order to anticipate, avoid, prevent, and/or detect an overflow or underflow from taking place in the transmitter buffer **267**.

The information amount counter **242** can be reset in response to a preset signal **254** generated and output by the controller **241**. After the information amount counter **242** is reset, it can count data output by the encoding unit **244** and obtain the amount of video compression data and/or video packets which have been generated. The information amount counter **242** can supply the controller **241** with an information amount signal **255** representative of the obtained amount of information. The controller **241** can control the encoding unit **244** so that there is no overflow at the transmitter buffer **267**.

In some embodiments, the decoding system **220** can comprise an input interface **266**, a receiver buffer **259**, a controller **267**, a frame memory **261**, a decoding unit **260** and an output interface **267**. The receiver buffer **259** of the decoding system **220** can temporarily store the compressed bit stream, including the received video compression data and video packets based on the source pictures from the source pictures **246**. The decoding system **220** can read the control information and presentation time stamp information associated with video packets in the received data and output a frame number signal **263** which can be applied to the controller **220**. The controller **267** can supervise the counted number of frames at a predetermined interval. By way of a non-limiting example, the controller **267** can supervise the counted number of frames each time the decoding unit **260** completes a decoding operation.

In some embodiments, when the frame number signal **263** indicates the receiver buffer **259** is at a predetermined capacity, the controller **267** can output a decoding start signal **264** to the decoding unit **260**. When the frame number signal **263** indicates the receiver buffer **259** is at less than a predetermined capacity, the controller **267** can wait for the occurrence of a situation in which the counted number of frames becomes equal to the predetermined amount. The controller **267** can output the decoding start signal **263** when the situation occurs. By way of a non-limiting example, the controller **267** can output the decoding start signal **264** when the frame number signal **263** indicates the receiver buffer **259** is at the predetermined capacity. The encoded video packets and video compression data can be decoded in a monotonic order (i.e., increasing or decreasing) based on presentation time stamps associated with the encoded video packets.

In response to the decoding start signal **264**, the decoding unit **260** can decode data amounting to one picture associated with a frame and compressed video data associated with the picture associated with video packets from the receiver buffer **259**. The decoding unit **260** can write a decoded video signal **269** into the frame memory **261**. The frame memory **261** can have a first area into which the decoded video signal is written, and a second area used for reading out decoded pictures **262** to the output interface **267**.

In various embodiments, the coding system **202** can be incorporated or otherwise associated with a transcoder or an encoding apparatus at a headend and the decoding system **220** can be incorporated or otherwise associated with a downstream device, such as a mobile device, a set top box or a transcoder.

Source Encoding/Decoding

As described above, the encoders **202** employ compression algorithms to generate bit streams and/or files of smaller size than the original video sequences in the AV information **102**. Such compression is made possible by reducing spatial and temporal redundancies in the original sequences.

Prior art encoders **202** include those compliant with the video compression standard H.264/MPEG-4 AVC ("Advanced Video Coding") developed by between the "Video Coding Expert Group" (VCEG) of the ITU and the "Moving Picture Experts Group" (MPEG) of the ISO, in particular in the form of the publication "Advanced Video Coding for Generic Audiovisual Services" (March 2005), which is hereby incorporated by reference herein.

HEVC "High Efficiency Video Coding" (sometimes known as H.265) is expected to replace the H.264/MPEG-4 AVC. HEVC introduces new coding tools and entities that are generalizations of the coding entities defined in H.264/AVC, as further described below, and as described in U.S. Provisional Application Nos. 61/562,418, 61/619,916, and 61/595,141.

FIG. **3** is a block diagram illustrating one embodiment of the source encoder **202**. The source encoder **202** accepts AV information **102** and uses sampler **302** sample the AV information **102** to produce a sequence **303** of successive of digital images or pictures, each having a plurality of pixels. A picture can comprise a frame or a field, wherein a frame is a complete image captured during a known time interval, and a field is the set of odd-numbered or even-numbered scanning lines composing a partial image.

The sampler **302** produces an uncompressed picture sequence **303**. Each digital picture can be represented by one or more matrices having a plurality of coefficients that represent information about the pixels that together comprise the picture. The value of a pixel can correspond to luminance or other information. In the case where several components are associated with each pixel (for example red-green-blue components or luminance-chrominance components), each of these components may be separately processed.

Images can be segmented into "slices," which may comprise a portion of the picture or may comprise the entire picture. In the H.264 standard, these slices are divided into coding entities called macroblocks (generally blocks of size

16 pixels×16 pixels) and each macroblock may in turn be divided into different sizes of data blocks **102**, for example 4×4, 4×8, 8×4, 8×8, 8×16, 16×8. HEVC expands and generalizes the notion of the coding entity beyond that of the macroblock.

HEVC Coding Entities: CTU, CU, PU and TU

Like other video coding standards, HEVC is a block-based hybrid spatial and temporal predictive coding scheme. However, HEVC introduces new coding entities that are not included with H.264/AVC standard. These coding entities include (1) Coding tree block (CTUs), coding units (CUs), the predictive units (PUs) and transform units (TUs) and are further described below.

FIG. **4** is a diagram depicting a picture **400** of AV information **102**, such as one of the pictures in the picture sequence **303**. The picture **400** is spatially divided into non-overlapping square blocks known as coding tree units(s), or CTUs **402**. Unlike H.264 and previous video coding standards where the basic coding unit is macroblock of 16×16 pixels, the CTU **402** is the basic coding unit of HEVC, and can be as large as 128×128 pixels. As shown in FIG. **4**, the CTUs **402** are typically referenced within the picture **400** in an order analogous to a progressive scan.

Each CTU **402** may in turn be iteratively divided into smaller variable size coding units described by a "quadtree" decomposition further described below. Coding units are regions formed in the image to which similar encoding parameters are applied and transmitted in the bitstream **314**.

FIG. **5** is a diagram showing an exemplary partition of a CTU **402** into coding units (CUs) such as coding unit **502**A and **502**B (hereinafter alternatively referred to as coding unit(s) **502**). A single CTU **402** can be divided into four CUs **502** such as CU **502**A, each a quarter of the size of CTU **402**. Each such divided CU **502**A can be further divided into four smaller CUs **502**B of quarter size of initial CU **502**A.

The division of CTUs **402** into CUs **502**A and into smaller CUs **502**B is described by "quadtree" data parameters (e.g. flags or bits) that are encoded into the output bitstream **314** along with the encoded data as overhead known as syntax.

FIG. **6** is a diagram illustrating a representation of a representative quadtree **600** and data parameters for the CTU **402** partitioning shown in FIG. **5**. The quadtree **600** comprises a plurality of nodes including first node **602**A at one hierarchical level and second node **602**B at a lower hierarchical level (hereinafter, quadtree nodes may be alternatively referred to as "nodes" **602**). At each node **602** of a quadtree, a "split flag" or bit "**1**" is assigned if the node **602** is further split into sub-nodes, otherwise a bit "**0**" is assigned.

For example, the CTU **402** partition illustrated in FIG. **5** can be represented by the quadtree **600** presented in FIG. **6**, which includes a split flag of "1" associated with node **602**A at the top CU **502** level (indicating there are 4 additional nodes at a lower hierarchical level). The illustrated quadtree **600** also includes a split flag of "1" associated with node **602**B at the mid CU **502** level to indicate that this CU is also partitioned into four further CUs **502** at the next (bottom) CU level. The source encoder **202** may restrict the minimum and maximum CU **502** sizes, thus changing the maximum possible depth of the CU **502** splitting.

The encoder **202** generates encoded AV information **106** in the form of a bitstream **314** that includes a first portion having encoded data for the CUs **502** and a second portion that includes overhead known as syntax elements. The encoded data includes data corresponding to the encoded CUs **502** (i.e. the encoded residuals together with their associated motion vectors, predictors, or related residuals as described further below). The second portion includes syntax elements that may represent encoding parameters which do not directly correspond to the encoded data of the blocks. For example, the syntax elements may comprise an address and identification of the CU **502** in the image, a quantization parameter, an indication of the elected Inter/Intra coding mode, the quadtree **600** or other information.

CUs **502** correspond to elementary coding elements and include two related sub-units: prediction units (PUs) and transform units (TUs), both of which have a maximum size equal to the size of the corresponding CU **502**.

FIG. **7** is a diagram illustrating the partition of a CU **502** into one or more PUs **702**. A PU **702** corresponds to a partitioned CU **502** and is used to predict pixels values for intra-picture or inter-picture types. PUs **702** are an extension of the partitioning of H.264/AVC for motion estimation, and are defined for each CU **502** that is not further subdivided into other CUs ("split flag"=0). At each leaf **604** of the quadtree **600**, a final (bottom level) CU **502** of 2N×2N can possess one of four possible patterns of PUs: 2N×2N (**702**A), 2N×N (**702**B), N×2N (**702**C) and N×N (**702**D)), as shown in FIG. **7**.

A CU **502** can be either spatially or temporally predictive coded. If a CU **502** is coded in "intra" mode, each PU **702** of the CU **502** can have its own spatial prediction direction and image information as further described below. Also, in the "intra" mode, the PU **702** of the CU **502** may depend on another CU **502** because it may use a spatial neighbor, which is in another CU. If a CU **502** is coded in "inter" mode, each PU **702** of the CU **502** can have its own motion vector(s) and associated reference picture(s) as further described below.

FIG. **8** is a diagram showing a CU **502** partitioned into four PUs **702** and an associated set of transform units (TUs) **802**. TUs **802** are used to represent the elementary units that are spatially transformed by a DCT (Discrete Cosine Transform). The size and location of each block transform TU **802** within a CU **502** is described by a "residual" quadtree (RQT) further illustrated below.

FIG. **9** is a diagram showing RQT **900** for TUs **802** for the CU **502** in the example of FIG. **8**. Note that the "1" at the first node **902**A of the RQT **900** indicates that there are four branches and that the "1" at the second node **902**B at the adjacent lower hierarchical level indicates that the indicated node further has four branches. The data describing the RQT **900** is also coded and transmitted as an overhead in the bitstream **314**.

The coding parameters of a video sequence may be stored in dedicated NAL units called parameter sets. Two types of parameter sets NAL units may be employed. The first parameter set type is known as a Sequence Parameter Set (SPS), and comprises a NAL unit that includes parameters that are unchanged during the entire video sequence. Typically, an SPS handles the coding profile, the size of the video frames and other parameters. The second type of parameter set is known as a Picture Parameter Set (PPS), and codes different values that may change from one image to another.

Spatial and Temporal Prediction

One of the techniques used to compress a bitstream **314** is to forego the storage of pixel values themselves and instead, predict the pixel values using a process that can be repeated at the decoder **220** and store or transmit the difference between the predicted pixel values and the actual pixel values (known as the residual). So long as the decoder **220** can compute the same predicted pixel values from the information provided, the actual picture values can be recovered by adding the residuals to the predicted values. The same technique can be used to compress other data as well.

Referring back to FIG. **3**, each PU **702** of the CU **502** being processed is provided to a predictor module **307**. The predictor module **307** predicts the values of the PUs **702** based on information in nearby PUs **702** in the same frame (intra-frame prediction, which is performed by the spatial predictor **324**) and information of PUs **702** in temporally proximate frames (inter-frame prediction, which is performed by the temporal predictor **330**). Temporal prediction, however, may not always be based on a collocated PU, since collocated PUs are defined to be located at a reference/non-reference frame having the same x and y coordinates as the current PU **702**. These techniques take advantage of spatial and temporal dependencies between PUs **702**.

Encoded units can therefore be categorized to include two types: (1) non-temporally predicted units and (2) temporally predicted units. Non-temporally predicted units are predicted using the current frame, including adjacent or nearby PUs **702** within the frame (e.g. intra-frame prediction), and are generated by the spatial predictor **324**. Temporally predicted units are predicted from one temporal picture (e.g. P-frames) or predicted from at least two reference pictures temporally ahead and/or behind (i.e. B-frames).

Spatial Prediction

FIG. **10** is a diagram illustrating spatial prediction of PUs **702**. A picture i may comprise a PU **702** and spatially proximate other PUs **1-4**, including nearby PU **702**N. The spatial predictor **324** predicts the current block (e.g. block C of FIG. **10**) by means of an "intra-frame" prediction which uses PUs **702** of already-encoded other blocks of pixels of the current image.

The spatial predictor **324** locates a nearby PU (e.g. PU **1**, **2**, **3** or **4** of FIG. **10**) that is appropriate for spatial coding and determines an angular prediction direction to that nearby PU. In HEVC, 35 directions can be considered, so each PU may have one of 35 directions associated with it, including horizontal, vertical, 45 degree diagonal, 135 degree diagonal, DC etc. The spatial prediction direction of the PU is indicated in the syntax.

Referring back to the spatial predictor **324** of FIG. **3**, this located nearby PU is used to compute a residual PU **704** (*e*) as the difference between the pixels of the nearby PU **702**N and the current PU **702**, using element **305**. The result is an intra-predicted PU element **1006** that comprises a prediction direction **1002** and the intra-predicted residual PU **1004**. The prediction direction **1002** may be coded by inferring the direction from spatially proximate PUs, and the spatial dependencies of the picture, enabling the coding rate of the intra prediction direction mode to be reduced.

Temporal Prediction

FIG. **11** is a diagram illustrating temporal prediction. Temporal prediction considers information from temporally neighboring pictures or frames, such as the previous picture, picture i−1.

Generally, temporal prediction includes single-prediction (P-type), which predicts the PU **702** by referring to one reference area from only one reference picture, and multiple prediction (B-type), which predicts the PU by referring to two reference areas from one or two reference pictures. Reference images are images in the video sequence that have already been coded and then reconstructed (by decoding).

The temporal predictor **330** identifies, in one or several of these reference areas (one for P-type or several for B-type), areas of pixels in a temporally nearby frame so that they can be used as predictors of this current PU **702**. In the case where several areas predictors are used (B-type), they may be merged to generate one single prediction. The reference area **1102** is identified in the reference frame by a motion vector (MV) **1104** that is defines the displacement between the current PU **702** in current frame (picture i) and the reference area **1102** (refIdx) in the reference frame (picture i−1). A PU in a B-picture may have up to two MVs. Both MV and refIdx information are included in the syntax of the HEVC bitstream.

Referring again to FIG. **3**, a difference between the pixel values between of the reference area **1102** and the current PU **702** may be computed by element **305** as selected by switch **306**. This difference is referred to as the residual of the inter-predicted PU **1106**. At the end of the temporal or inter-frame prediction process, the current PU **1006** is composed of one motion vector MV **1104** and a residual **1106**.

However, as described above, one technique for compressing data is to generate predicted values for the data using means repeatable by the decoder **220**, computing the difference between the predicted and actual values of the data (the residual) and transmitting the residual for decoding. So long as the decoder **220** can reproduce the predicted values, the residual values can be used to determine the actual values.

This technique can be applied to the MVs **1104** used in temporal prediction by generating a prediction of the MV **1104**, computing a difference between the actual MV **1104** and the predicted MV **1104** (a residual) and transmitting the MV residual in the bitstream **314**. So long as the decoder **220** can reproduce the predicted MV **1104**, the actual MV **1104** can be computed from the residual. HEVC computes a predicted MV for each PU **702** using the spatial correlation of movement between nearby PUs **702**.

FIG. **12** is a diagram illustrating the use of motion vector predictors (MVPs) in HEVC. Motion vector predictors V**1**, V**2** and V**3** are taken from the MVs **1104** of a plurality of blocks **1**, **2**, and **3** situated nearby or adjacent the block to encode (C). As these vectors refer to motion vectors of spatially neighboring blocks within the same temporal frame and can be used to predict the motion vector of the block to encode, these vectors are known as spatial motion predictors.

FIG. **12** also illustrates temporal motion vector predictor VT which is the motion vector of the co-located block C' in a previously decoded picture (in decoding order) of the sequence (e.g. block of picture i−1 located at the same spatial position as the block being coded (block C of image i).

The components of the spatial motion vector predictors V**1**, V**2** and V**3** and the temporal motion vector predictor VT can be used to generate a median motion vector predictor VM. In HEVC, the three spatial motion vector predictors may be taken as shown in FIG. **12**, that is, from the block situated to the left of the block to encode (V**1**), the block situated above (V**3**) and from one of the blocks situated at the respective corners of the block to encode (V**2**), according to a predetermined rule of availability. This MV predictor selection technique is known as Advanced Motion Vector Prediction (AMVP).

A plurality of (typically five) MV predictor (MVP) candidates having spatial predictors (e.g. V**1**, V**2** and V**3**) and temporal predictor(s) VT is therefore obtained. In order to reduce the overhead of signaling the motion vector predictor in the bitstream, the set of motion vector predictors may reduced by eliminating data for duplicated motion vectors (for example, MVs which have the same value as other MVs may be eliminated from the candidates).

The encoder **202** may select a "best" motion vector predictor from among the candidates, and compute a motion vector predictor residual as a difference between the selected motion vector predictor and the actual motion vector, and transmit the motion vector predictor residual in the bitstream **314**. To perform this operation, the actual motion vector must be stored for later use by the decoder **220** (although it is not transmitted in the bit stream **314**. Signaling bits or flags are included in the bitstream **314** to specify which MV residual was computed from the normalized motion vector predictor, and are later used by the decoder to recover the motion vector. These bits or flags are further described below.

Referring back to FIG. **3**, the intra-predicted residuals **1004** and the inter-predicted residuals **1106** obtained from the spatial (intra) or temporal (inter) prediction process are then transformed by transform module **308** into the transform units (TUs) **802** described above. A TU **802** can be further split into smaller TUs using the RQT decomposition described above with respect to FIG. **9**. In HEVC, generally 2 or 3 levels of decompositions are used and authorized transform sizes are from 32×32, 16×16, 8×8 and 4×4. As described above, the transform is derived according to a discrete cosine transform (DCT) or discrete sine transform (DST).

The residual transformed coefficients are then quantized by quantizer **310**. Quantization plays a very important role in data compression. In HEVC, quantization converts the high precision transform coefficients into a finite number of possible values. Although the quantization permits a great deal of compression, quantization is a lossy operation, and the loss by quantization cannot be recovered.

The coefficients of the quantized transformed residual are then coded by means of an entropy coder **312** and then inserted into the compressed bit stream **310** as a part of the useful data coding the images of the AV information. Coding syntax elements may also be coded using spatial dependencies between syntax elements to increase the coding efficiency. HEVC offers context-adaptive binary arithmetic coding (CABAC). Other forms or entropy or arithmetic coding may also be used.

In order to calculate the predictors used above, the encoder **202** decodes already encoded PUs **702** using "decoding" loop **315**, which includes elements **316**, **318**, **320**, **322**, **328**. This decoding loop **315** reconstructs the PUs and images from the quantized transformed residuals.

The quantized transform residual coefficients E are provided to dequantizer **316**, which applies the inverse operation to that of quantizer **310** to produce dequantized transform coefficients of the residual PU (E') **708**. The dequantized data **708** is then provided to inverse transformer **318** which applies the inverse of the transform applied by the transform module **308** to generate reconstructed residual coefficients of the PU (e') **710**.

The reconstructed coefficients of the residual PU **710** are then added to the corresponding coefficients of the corresponding predicted PU (x') **702'** selected from the intra-predicted PU **1004** and the inter-predicted PU **1106** by selector **306**. For example, if the reconstructed residual comes from the "intra" coding process of the spatial predictor **324**, the "intra" predictor (x') is added to this residual in order to recover a reconstructed PU (x") **712** corresponding to the original PU **702** modified by the losses resulting from a transformation, for example in this case the quantization operations. If the residual **710** comes from an "inter" coding process of the temporal predictor **330**, the areas pointed to by the current motion vectors (these areas belong to the reference images stored in reference buffer **328** referred by the current image indices) are merged then added to this decoded residual. In this way the original PU **702** is modified by the losses resulting from the quantization operations.

To the extent that the encoder **202** uses motion vector prediction techniques analogous to the image prediction techniques described above, the motion vector may be stored using motion vector buffer **329** for use in temporally subsequent frames. As further described below, a flag may be set and transferred in the syntax to indicate that the motion vector for the currently decoded frame should be used for at least the subsequently coded frame instead of replacing the contents of the MV buffer **329** with the MV for the current frame.

A loop filter **322** is applied to the reconstructed signal (x") **712** in order to reduce the effects created by heavy quantization of the residuals obtained, and to improve the signal quality. The loop filter **322** may comprise, for example, a deblocking filter for smoothing borders between PUs to visually attenuate high frequencies created by the coding process and a linear filter that is applied after all of the PUs for an image have been decoded to minimize the sum of the square difference (SSD) with the original image. The linear filtering process is performed on a frame by frame basis and uses several pixels around the pixel to be filtered, and also uses spatial dependencies between pixels of the frame. The linear filter coefficients may be coded and transmitted in one header of the bitstream typically a picture or slice header.

The filtered images, also known as reconstructed images, are then stored as reference images from reference image buffer **328** in order to allow the subsequent "Inter" predictions taking place during the compression of the subsequent images of the current video sequence.

Entropy Coding

The coding performed by coder **312** is performed by coding each coefficient of the quantized transform coefficients of the transform unit (TU) **802** obtained from the transformer **308** and quantizer **310**. Such coding is typically performed for each transform coefficient or group of coefficients using one of a plurality of available scan patterns.

FIG. **13** is a diagram illustrating exemplary scan patterns used for coding of the quantized coefficients of a non-square (4×6) TU **802**. These scan patterns include a horizontal scan pattern **1302**A (scan angle θ=0 degrees), zig-zag, diagonal patterns **1302**B and **1302**D (scan angle θ=45 and 135 degrees), and vertical scan **1302**C (scan angle=270 degrees). Wavefront scanning (in which the encoder **312** uses information from the preceding row of TUs **802**, enabling parallel processing that may allow for better compression than simple tiling) may be performed in any direction.

The illustrated scan patterns begin at the TU **802** coefficient at the upper right of each TU **802** and ends at the lower right coefficient of the TU **802**. However, the scan pattern may begin at the lower right coefficient 24 and end at the upper left coefficient 1, or for that matter, may follow a pattern from the innermost coefficient positions to the outermost coefficient positions, following a clockwise (e.g. 10, 11, 14, 15, 19, 18, 17, 13, 9, 5, 6, 7, 8, 12, 16, 20, 24, 23, 22, 21, 1, 2, 3, 4) or counter-clockwise pattern or a pattern that follows the outermost coefficient positions inward. Further, the scan pattern need not be continuous (e.g. 10, 15, 14, 11, etc.). As will be described further below, once the last significant (non-zero) coefficient position is known, the coefficients can be decoded in the opposite direction of the scan pattern back to the first coefficient in the scan pattern.

FIG. **14**A is a diagram of an exemplary TU **802** coefficient map **1402**. Note that many of the coefficients are zero coefficients (e.g. their value is zero). For each TU **802** and at each scanned position, a bit may be assigned or set to indicate if the corresponding coefficient is zero or not, resulting in a significance map **1452** that is associated with each TU **802**.

FIG. **14**B is a diagram showing an exemplary significance map **1452** of the TU **802** coefficients illustrated in FIG. **14**A. Non-zero coefficients are indicated with a logical 1 and zero coefficients are indicated with a logical 0 (although a different mapping may be used).

Returning to the example of FIG. **14**A, if the scan pattern is a horizontal scan pattern **1302**A, the last non-zero coefficient of the TU **802** is coefficient **1404**. This can also be seen in FIG. **14**B, as the significance map element associated with coefficient **1404** is a logical 1 and is the last element in the horizontal scan pattern **1202**A.

Regardless of which scan technique or pattern is used, all quantized coefficients must be scanned, except those along the scan pattern that are beyond the last coded coefficient of a TU **802**. However, as HEVC is currently defined, it is possible that all of the coefficients of the TU **802** will be scanned unless there is a reliable means for identifying and skipping the remainder of the coefficients after the last non-zero coefficient in the scan pattern. Ideally, the means for identifying the last non-zero coefficient should strike a balance between minimizing processing and the size of the resulting bitstream **314**.

As described above with reference to the encoder **312** illustrated in FIG. **3**, HEVC implements context adaptive coding such as context adaptive binary arithmetic coding (CABAC). CABAC is a form of entropy encoding that encodes binary symbols using probability models. A non-binary valued symbol (such as a transform unit coefficient or motion vector) is binarized or converted into a binary code prior to arithmetic coding. Stages are repeated for each bit (or "bin") of the binarized symbol.

A context model is a probability model for one or more bins of the binarized symbol. This model may be chosen from a plurality of available models depending on the statistics of recently-coded data symbols. The context model stores the probability of each bin being "1" or "0". An arithmetic coder then encodes each bin according to the selected probability model.

A context variable is a variable specified for the adaptive binary arithmetic decoding process of a bin by an equation containing recently decoded bins. A cabac_init_flag specifies the method for determining the initialization table used in the initialization process for context variables. The value of cabac_init_flag is in the range of 0 to 1, inclusive. When cabac_init_flag is not present, it is inferred to be 0.

The initialization of context variables is performed as follows. For each context variable, the two variables pStateIdx (probability state index) and valMPS (value of most probable symbol) are initialized. From a table entry initValue, the two 4 bit variables (slopeIdx and intersecIdx) are derived according to the following pseudo-code process:

```
slopeIdx = initValue >> 4
intersecIdx = initValue & 15
   Slope m and Intersec n are derived from the indices as follows:
m = slopeIdx*5 − 45
n = ( intersecIdx << 3 ) − 16
```


The last significant coefficient of a TU **802** in a scan pattern may identified by the variables last_significant_coeff_x and last_significant_coeff_y.

FIG. **15**A presents a table for determining the initialization variables m and n according to the last_significant_coeff_x and last_significant_coeff_y variables. For 16×16 TU **802**, the range of the variables last_significant_coeff_x and last_significant_coeff_y is from 0 to 15. The coefficients for the first half of the position range (0-7) are decoded using context based model as indicated. Six contexts are used for the luminescence (Luma) 16×16 TU. That is, ctxIdx 6-11 are for I-type intra coded pictures, ctxIdx 37-42 are for P-type inter coded pictures, and ctxIdx 68-73 are for B-type inter coded picture. FIG. **15**B presents a table showing the ctxIdx offset for different CU **502** typed.

For 32×32 TU **802**, the last_significant_coeff_x and last_significant_coeff_y range from 0 to 31. The first half of the position (range 0-15) are decoded using context based model in the table shown in FIG. **15**A. Seven contexts are used for a Luma 32×32 TU. That is, ctxIdx 12-18 are for I-type intra coded pictures, ctxIdx 43-49 are for P-type inter coded pictures, and ctxIdx 74-80 are for B-type inter-coded pictures. Further, the possible range of either the last_significant_coeff_x or last_significant_coeff_y for rectangular TUs **802** (32×8, 8×32, 16×4, and 4×16) is the value for the maximum of the longest dimension of the TU **802**. Hence, generally, the range of either last_significant_coeff_x or last_significant_coeff_y could be from 0-31 for any M×N TU where max(M,N) is larger than 16.

Scanning all of the TU **802** coefficients, even those with a value of zero causes the encoder **312** to perform additional calculations and the encoder **312** to perform additional calculations and to send more bits in the bitstream **314** than are necessary for the decoding process. Further exacerbating the problem, the probability of having a scan row, column, or diagonal with only zero coefficients may be higher with the non-square TUs **802** introduced in HEVC.

Further, because of the large range (0-31) of last_significant_coeff_x and last_significant_coeff_y, the last coefficient position coding requires a large number of bits to code two numbers from 0-31 and a large number of contexts and bins to support multiple TU **802** sizes as shown in FIG. **15**A.

Last Coefficient Coding and Decoding

One technique to reduce the size of the bitstream **314** and the bins necessary for the coding of the quantized TU **802** coefficients is to encode a flag in the bitstream syntax that indicates when a particular portion of the TU **802** coefficients in a portion of the scan pattern has at least one non-zero coefficient. Generally, this technique introduces a flag for a scan row, column or diagonal (for diagonal, maybe only certain size will have that flag), depending the scan pattern. If a scan row, column, or diagonal has only zero coefficients, the flag is set to be 0; otherwise, 1. This introduced flag uses fewer bits than directly encoding the last significant coefficient of the transform unit, while maintaining adequate performance. To further reduce the overhead of flag bits, the number of set flags may be reduced by not setting any flags for remaining rows or columns in the scan pattern if they have all zero coefficients. The flag bit overhead can be still further reduced because the last row or column may be inferred from the flag for the preceding row or column. These features are described in more detail below.

FIG. **16**A is diagram presenting an exemplary technique for performing a last coefficient coding technique that can be used in an HEVC encoding/decoding system **202**. In block

1602, a determination is made as to whether all of the coefficients of a portion of the TU 802 disposed on a portion of a scan pattern in zero. Block 1604 sets a flag associated with the portion of the TU 802 to a first value if at least one of the coefficients of the portion of the TU 802 on the portion of the scan pattern is non-zero. Block 1606 sets a flag associated with the portion of the TU 802 to a second value if all of the coefficients of the portion of the TU 802 on the portion of the scan pattern are zero. Block 1608 determines if all of the scan portions have been considered. If not, processing passes back to block 1602 for consideration of the next portion of the TU 802 coefficients on the next portion of the scan pattern. If all of the scan portions have been considered, processing for the instant last coefficient processing for the TU under consideration is completed, and processing for the next TU or other task may begin. Block 1610 is optional further embodiment that is further discussed below.

FIG. 17 is a diagram illustrating the operations of FIG. 16A. For purposes of simplicity, FIG. 17 discloses an embodiment using the horizontal scan pattern 1302A illustrated in FIG. 13. In this scan pattern 1302A, a first portion of the TU 802 coefficients (e.g. those in the first row) on the first portion 1702A of the scan pattern includes at least one non-zero coefficient, namely, the zeroth and fifth coefficients of scan portion 1702A. Therefore, block 1604 sets first flag 1706A associated with the first portion of TU 802 coefficients on the first portion of the scan pattern 1702A to a logical 1.

Block 1608 determines that there are more scan portions remaining in the scan pattern (e.g. scan pattern portions 1702B-1702H), so processing is routed back to block 1602, which again determines if there is at least one non-zero coefficient the portion of the TU 802 transform coefficients of the next scan pattern portion 1702B. In the illustrated example, the second portion 1702 of the scan pattern 1302A also includes at least one non-zero coefficient (the second coefficient), hence, block 1604 sets a second flag 1706B associated with the second portion 1702B of the transform coefficients on a second portion of the scan pattern 1302A.

Again, block 1608 determines that there are more scan portions 1702C-1702H remaining in the scan pattern 1302A, so processing is routed to block 1602 and third portion 1702C of the coefficients of the TU 802 are examined. In this case, all of the coefficients of the third portion of the TU on the third portion 1702C of the scan patter 1302A are zero, so block 1606 sets third flag 1706C to zero, indicating that that portion of the scan pattern 1302A includes TU 802 coefficients that are all zero.

This process is repeated until all of the coefficients of the TU 802 have been examined, and a flag has been set or not set to indicate whether the associated scan portion 1702A-1702H (and portion of TU 802 coefficients) have any non-zero values. In the illustrated embodiment, the since flag 1706A, 1706V, 1706D, and 1706F have a value of one, it is known that at least one of these scan portion coefficients (in this case, rows) have a non-zero value. That the remaining flags have a value of zero indicates that those scan portion coefficients all have a value of zero.

Although the scan pattern 1302A for this example is a row-by-row can pattern for purposes of illustrative simplicity, the same technique can be used for any scan pattern, including column-by-column scanning 1302C, either of the diagonal scan patterns 1302B and 1302D, wavefront scanning, or even circular or non-continuous scan patterns. All that is required is that a flag or other artifice be set to a value indicating the zero/non-zero status of an associated portion of the TU 802 coefficients on an associated portion of the scan pattern 1302.

The entropy coding of the TU 802 coefficients themselves may be performed after each individual coefficient is examined to determine whether it has a non-zero value, after the entire scan portion (e.g. row, column, or diagonal) has been examined to determine whether there are any non-zero coefficients (for example, after block 1602 or block 1606 of FIG. 16A) or after the entire TU 802 has been scanned to determine whether there are any non zero coefficients (after the operations shown in FIG. 16A have all been completed). By indicating the last scan portion 1702F that includes a non-zero value, the foregoing paradigm allows the encoder and decoder to forego the decoding of TU 802 coefficients that have zero values, thus saving bits in the bitstream 314 and the associated processing required to decode the encoded TU 802 coefficients. In one embodiment, the flags 1706 described above may be known as last_TU_scan_portion flags, which are sent in the syntax and associated with the TU 802.

Indicating the last non-zero coefficient in the scan pattern by a simple number or two numbers analogous to Cartesian coordinates (e.g. last_significant_coeff_x and last_significant_coeff_y) can also result in bitstream 314 and processing savings. However, particularly with the larger TUs made possible under HEVC, (which can be as large as 32×32), a significant number of bits are wasted. The foregoing technique allows the processing of zero coefficients to be reduced, while substantially reducing the number of bits required in the bitstream 314 for last coefficient signaling.

While the foregoing reduces the number of zero value TU 802 coefficients to be encoded, it still may result in some number of zero value TU 802 coefficients to be encoded, for example, the last two coefficients in row 1702F. This number may be further reduced by setting an additional flag (for example, a last_scan_portion_position flag) associated only with the last scan portion that indicates that the particular coefficient is the last coefficient 1704 in the last portion of the scan pattern to have a non-zero value.

Further, while the foregoing example used a flag as an indicator of the existence of a non-zero coefficient in the scan portion, any analogous artifice can be used for such signaling. For example, an index or other value can be used.

The number of bits required to indicate that last scan portion can be further reduced, as indicated by dashed block 1610 of FIG. 16A. Block 1610 determines whether all of the coefficients of the remaining portions of the TU 802 are zero. If not (non-zero coefficients remain in the remainder of TU 802 and scan portions), block 1612 allows processing to be routed to block 1604 to consider the next scan portion, as before. However, if all of the coefficients of the remaining portion of the TU 802 are zero, coding of TU 802 under consideration is ceased.

Referring back to the example presented in FIG. 17, the processing of scan portions 1702A-1702E proceed as before, and flags 1706A-1706E are set as indicated in the diagram. However, after flag 1706E is set, processing is routed to block 1608, which determines that there are more portions of the scan pattern to be considered, and processing is thereby routed back to block 1602. Block 1602 determines that there is at least one non-zero coefficient in scan pattern portion 1702F (in fact, there are two). Next, processing is passed to block 1610, which considers whether the coefficients of all of the remaining portions of the TU 802 (e.g. the coefficients in scan portions 1702G and 1702H are equal to zero. In the example shown in FIG. 17, all of the remaining portions of the TU 802 have zero coefficients, so block 1610 routes processing to link A, which ends the last coefficient processing for the TU 802 under consideration. The resulting set of last coefficient flags associated with the TU belong to a last coefficient flag set **1708** which now excludes flags associated with scan portions **1702**G and **1702**H. This saves three bits of information otherwise used in the baseline embodiment. Note that this technique also saves an additional bit over simply foregoing the addition of any trailing zero flags such as flags **1706**G and **1706**H to the last coefficient flag set when the last two scan portions **1702**G and **1702**H have all zero coefficients. This is possible because the information conveyed by the fact that flag **1706**E is the last flag in the set of last coefficient flags is sufficient to infer that the next row or portion of the scan is the last portion with a non-zero TU coefficient.

FIG. **16**B is a diagram illustrating the decoding of the encoded bitstream **314**, using the last coefficient coding. In block **1652**, a flag **1706** associated with all of the coefficients of a first portion of a TU **802** disposed on a first portion of a scan pattern is read. If the flag **1706** has the first value, the first portion of the TU **802** coefficients disposed in the first portion of the scan pattern are decoded, as shown in block **1654**. If the flag **1706** has a second value, the coding of the first portion of TU **802** coefficients disposed on the first portion of the scan pattern **1702**A is skipped, as shown in block **1656**. Block **1662** checks to determine if there are any more scan portions **1702** in the TU **802**. If there are additional scan portions **1702**, processing is routed back to block **1652**, whereas if there are no additional scan portions, decoding processing for the TU **802** under consideration is terminated.

For example, referring back to FIG. **17**, flag **1706**A indicates that there is a non-zero coefficient in the first portion **1702**A of the scan pattern. Accordingly, processing is routed to block **1654**, and the first portion of the TU coefficients (those in the scan row portion **1702** are decoded. The process is completed for scan pattern portion **1702**B because flag **1706** is also set to one, indicating that there is a non-zero coefficient value in the TU **802** coefficients of the second scan pattern portion **1702**B. Flag **1706**C indicates that all coefficients in scan pattern portion **1702**C have the second value, and decoding of the associated coefficients of the TU **802** in the scan portion **1702**C is skipped. This process is repeated for the remaining flags **1706**D-**1706**H.

Dashed blocks **1658** and **1662** refer decoding using the optional embodiment introduced in block **1610** of FIG. **16**A. Block **1658** determines whether the read flag is the last remaining flag of a flat set **1708**. If either the read flag **1706** is not the last remaining flag of the flag set, processing is routed to block **1662** and is continues as previously described. But if the read flag is the last remaining flag of the flag set, the portion of the TU **802** coefficients associated with the portion of the scan pattern **1702** following the current scan portion **102** associated with the remaining flag are decoded, and coding of the remaining coefficients of the TU **802** is skipped, as shown in block **1664**.

For example, referring again to FIG. **17**, the last remaining flag of the flag set **1708** is flag **1708**E, which has a value of zero. Since this is the last remaining flag of the flag set **1708**, block **1664** decodes the coefficients of the portion of the TU **802** following the portion associated with the last remaining flag **1706**E (which includes the coefficients in scan pattern portion **1702**F, and skips the decoding of the remaining coefficients in the TU **802** being decoded, including the coefficients in scan portions **1702**G and **1702**H.

In the examples presented, the coding and decoding of the TU **802** coefficients and the setting of the flags **1706** or **1708** was performed following the scan pattern **1302**A in the direction. As described in FIG. **16**B, the decoding of the coefficients can be performed in the same direction, or may be coded in an opposite direction from the scan pattern.

For example, referring to FIG. **17**, the decoding of the encoded TU **802** coefficients can be performed by starting from scan portion **1702**H, the last scan portion. Flags **1706**H and **1706**G indicate that scan portions **1702**H and **1702**G have all zero TU **802** coefficients, so the decoding of the coefficients in these scan pattern portions, if they are in the bitstream **314** at all, can be skipped. Flag **1706**F indicates that scan pattern portion **1702**F includes some non-zero coefficients, so the coefficients of this portion of the TU **802** can be decoded. This process can then continue for the remainder of the TU **802** coefficients. Or, logic can be inserted prior to block **1652** that determines the last flag associated with the scan pattern that has the first value (e.g. **1706**F), and simply begin decoding of the coefficients of the scan portion associated with that flag (e.g. **1706**F) and the remaining scan portions of the TU **802** prior to that scan portion (e.g. **1702**E-**1702**A).

Similarly, in the alternative embodiment shown in the dashed blocks of FIGS. **16**A and **16**B, the last flag **1708**E of the flag set **1708** indicates that the last scan pattern portion **1702** with a non-zero TU **802** coefficient is the scan pattern portion that follows the scan pattern portion associated with the last flag **1708**, or scan pattern portion **1702**F. Decoding of the TU coefficients can therefore begin with the TU **802** coefficients in scan pattern portion **1702**F and end with scan pattern portion **1702**A.

The illustrations used to describe the foregoing used a row by row scan pattern such as is illustrated in **1302**A of FIG. **13**. It is noted, however, that the technique itself can be performed with a diagonal scan pattern or any scan pattern, so long as the appropriate flag is associated with the portion of the scan pattern. It is also noted that a rule can be imposed for diagonal scan patterns (or others in which the number of coefficients in the scan pattern vary from portion to portion) in which the flag indicating the zero/non-zero status of the in the scan portion is only used when the scan portion has a minimum number of coefficients.

Last Coefficient Group Position Encoding and Decoding

Another technique to reduce the size of the bitstream **314** and the bins necessary for the coding of the quantized TU **802** coefficients is to encode a flag in the bitstream syntax that indicates when a particular portion or group of TU **802** coefficients in a portion of a scan pattern has at least one non-zero coefficient.

FIG. **18**A is a diagram of 16×16 TU **802** having a plurality of coefficients **1802**, and FIG. **18**B is a significance map generated from the TU **802** illustrated in FIG. **18**A. The significance map **1820** has a "1" in each coefficient position having a non-zero value.

The TU **802** shown in FIG. **18**A may be scanned and encoded coefficient-by-coefficient using a diagonal scan pattern **1824** analogous to the scan pattern of **1302**A, as shown in FIG. **18**C. Note that the last non-zero coefficient **1822** is located in the 12th position in the x direction and the 10th position in the y direction. Since the remaining coefficients are zero, they need not be entropy encoded, nor need they be decoded by the decoder **258**. By not encoding these coefficients, the bitstream **314** is correspondingly reduced and the processing required at both the encoder **240** and decoder **258** can be reduced. To implement this functionality, the last non-zero coefficient **1822** of the TU **802** in the scan pattern **1824** is indicated in the syntax associated with the TU **802** in Cartesian coordinates using variables known as last_significant_coeff_x and last_significant_coeff_y. These values are passed in the bitstream **314** along to the decoder. In the example shown in FIG. **18**C, last_significant_coeff_x=12 and last_significant_coeff_y=10.

The scan pattern **1824** may also be performed in the opposite direction shown in FIG. **18**C, but along the same path, beginning with the last coefficient of the scan path **1824**. This permits the position of the last significant coefficient **1822** to be determined more rapidly and by considering fewer coefficients.

The problem is that since the TU **802** can be as large as 32×32, the coding of the last_significant_coeff_x and last_significant_coeff_y variables requires a significant number of bits. To provide analogous functionality while requiring fewer bits, a two-level significance map may be adopted, which partitions TUs **802** larger than a specific size (for example, 16×16) into non-overlapping portions known as subblocks of the same size (e.g. 4×4).

FIG. **18**D is a diagram illustrating a TU **802** that has been partitioned into sixteen non-overlapping subblocks **1822**A-**1822**P, each subblock **1822** having the same 4×4 dimension and each including sixteen coefficients. The resulting partitioned TU **802** permits the definition of a multi-level significance map coding for the TU **802** that includes a level zero (L0) significance map and level one (L1) significance map.

The L0 significance map indicates which coefficients within a TU **802** are nonzero coefficients. If a coefficient is a non-zero coefficient, a significant_coeff_flag associated with the coefficient is set to a first value, such as "1". Otherwise, the significant_coeff_flag associated with that coefficient is set to a second value, such as "0". FIG. **18**B is a diagram showing an exemplary L0 significance map **1830** for the TU **802** shown in FIG. **18**A.

The L1 significance map indicates which 4×4 subblocks within a TU **802** contain at least one non-zero coefficient. If a 4×4 subblock (for example, subblock **1832**A) has at least one nonzero coefficient, a significant_coeffgroup_flag associated with that subblock is set to a first value such as a "1". Otherwise, (for example, subblock **1832**P) the significant_coeffgroup_flag is set to a second value such as a "0".

FIG. **18**E is a diagram of an L1 significance map **1840** corresponding to the partitioned TU **802** of FIG. **18**D. Note that the dashed subblocks of the TU **802** illustrated in FIG. **18**D (subblocks **1832**D, **1832**H, and **1832**M-**1832**P) each have all zero coefficients, and that this is reflected by the significant_coeffgroup_flag associated with the related portions of the L1 significance map **1840** having a value of "0". Note also that the remaining subblocks have at least one non-zero coefficient and thus subblocks **1832**A-**1832**C, **1832**E-**1832**G, and **1832**I-**1832**L each have an associated significant_coeffgroup_flag with a value of "1".

Also note that if the subblocks **1842**A-**1842**P were scanned using the diagonal subblock scan pattern **1832** analogous to the scan pattern of **1302**A (e.g. diagonally and subblock-by-subblock) as shown in FIG. **18**E, subblock **1832**L is the last subblock in the subblock scan pattern of the TU **802** to have a non-zero coefficient therein. This subblock **1832**L is known as the last significant subblock **1832**.

The position of the last significant subblock **1832**L may be computed and coded in the bitstream **314**. In one embodiment, the last significant subblock **1832**L position is expressed in terms of the horizontal and vertical position from the upper leftmost subblock **1832**A, using variables last_significant_subblock_coeff_x and last_significant_subblock_coeff_y. In the exemplary L1 significance map and scan pattern of FIG. **18**E, (last_significant_subblock_coeff_x, last_significant_subblock_coeff_y) is (3,2). Using subblocks of coefficients rather than coefficients to define the position reduces the range of the stored variables from 0-3 to 0-15 for a 16×16 TU **802**, and generating a L1 significance map only up to the last significant subblock **1832**L along the subblock scan pattern **1834** permits further savings.

The position of the last significant subblock **1832**L can be expressed in other terms, for example, in the number of subblocks **1832** along the subblock scan path **1834** from the first subblock in the scan pattern **1832**A.

FIG. **19** is a diagram presenting an exemplary technique for performing a last subblock coding technique that can be used in an HEVC encoding/decoding system **202**. In block **1902**, the last subblock **1832**L along a subblock processing scan pattern **1834** that has at least one non-zero TU coefficient (e.g. the last significant subblock) is determined. In block **1904**, the position of the determined last significant subblock **1832**L is encoded. As described above, the position of the last significant encoded subblock **1832**L may be encoded as last_significant_subblock_coeff_x and last_significant_subblock_coeff_y values, or by other syntax.

Turning next to block **1908**, a first value is encoded for each subblock preceding the last significant subblock in the subblock processing pattern that has at least one non-zero coefficient. For example, in FIG. **18**E, the last significant subblock **1832** is subblock **1832**L, and the each of the preceding subblocks in the scan pattern **1834** (e.g. subblocks **1832**A-**1832**O) are examined to determine which of those subblocks include a non-zero TU **802** coefficient. Subblocks having a non-zero TU **802** coefficient (e.g. subblocks **1832**A-**1832**C, **1832**E-**1832**G, and **1832**I-**1832**K) are encoded with a first value (in the illustrated example, "1"). Note that the a value for the last significant subblock **1832**L may also be encoded as "1" but need not be so, because that subblock, by definition, has a non-zero coefficient.

FIG. **18**F is a diagram illustrating a modified L1 significance map (or subblock significance map) generated using the foregoing paradigm. Note that since subblock **1832**P follows the last significant subblock **1832**L in the subblock scan path **1834**, it is known that this subblock **1832**P has no non-zero coefficients, and there coding of a "1" or a "0" for this block can be skipped, thus saving the bits that may be used encode this information. Also, note that a first value ("1") is not coded for the last significant subblock **1832**L, as the fact that it includes non-zero coefficients is already known. In alternate embodiments, a first value may be encoded for this subblock, if desired.

Block **1912** encodes the coefficients **1802** of the last significant subblock **1832**L and the coefficients of the subblocks **1832** preceding the last significant subblock **1832**L along the subblock scan pattern **1834** having the first encoded value ("1").

In the example shown in FIG. **18**F, the coefficients of last significant subblock **1832**L are encoded and the coefficients of subblocks **1832**A-**1832**C, **1832**E-**1832**G, and **1832**I-**1832**K and **1832**M-**1832**O along subblock scan path **1834** are also encoded. The encoding of subblocks **1832**D, **1832**H, **1832**M-**1832**O may be skipped (as shown in block **1914**) as they are known to include no non-zero coefficients (since they are not associated with the first encoded value ("1") but rather the second encoded value ("0"). The encoding of block **1832**P may also be skipped because it follows the last significant subblock **1832**L in the subblock scan pattern, and is therefore known not to have any non-zero coefficients.

The foregoing can be accomplished in order of the subblock scan pattern **1834** (e.g. from the first subblock in the scan pattern **1832**A to the last significant subblock **1832**L) or may be accomplished in reverse order (from the last significant subblock **1832**L and proceeding to the first subblock **1832**A in the subblock scan pattern **1834**).

FIG. **20** presents a diagram illustrating the coefficients of a candidate subblock having the first encoded value indicating that it includes non-zero coefficients. One such subblock **1832** is subblock **1832**A, which is illustrated in the diagram. The coefficients **1802** of each subblock are scanned and encoded following a coefficient scan pattern **2002**. The coefficient scan pattern **2002** illustrated in FIG. **20** follows an analogous scan pattern to the subblock scan pattern **1834**, but this not need be the case, as the coefficient scan pattern **2002** may differ from the subblock scan pattern **1834**. Further, although the coefficient scan pattern **2002** illustrated in FIG. **20** is indicated as being scanned from the top-leftmost coefficient **1802**A to the lower rightmost coefficient **1802**P, this need not be the case, as the direction may be reversed.

The coding of the coefficients themselves may be performed as shown in FIG. **18**G. In this embodiment, a significance map **1820** for the coefficients of the subblock under consideration (in the illustrated case, subblock **1832**A) is generated, resulting in a corresponding portion of the significance map **1820** (illustrated as item **1820**A) for the entire TU **820**. The difference between the portion of the coefficients **1832**A and the significance map **1820**A is obtained and used as the coded coefficients **1850**A. For example, the first row of the first subblock **1832**A has the values (5, 2, 0, 1). These corresponding significant map **1820** (1, 1, 0, 1) values may be subtracted from the TU **820** values to produce the values (4, 1, –, 0), and these resulting values may be further coded. This allows the same information to be conveyed while using fewer bits. Note that the zero-valued coefficients of the subblock **1832**A are not encoded during this process, but the non-zero coefficients are coded.

Note that the significance map **1820** for the TU **802** may be generated as a part of the encoding process. However, using the foregoing techniques, the significance map **1820** may be generated only for the last significant subblock **1832**L and the subblocks that precede it in the subblock scan pattern **1834**.

The aforementioned technique can be applied only to TUs **802** exceeding a particular size or dimension, for example, 16×16, 16×4, 4×16, 32×32, 32×8 and 8×32. For a generalized M×N TU **802**, coding the last significant subblock position using the two-level significance map instead of the last significant coefficient position:

1. Reduces the range of the last significant position: If a 16×16 TU **802** is divided into 4×4 subblocks, the range of the last coded position is reduced from 0-15 for the last significant coefficient values to 0-3 for 16×N or N×16 TU **802** for the last significant subblock values. Similarly, the range of the last coded position is reduced from 0-31 to 0-7 for 32×N or N×32 TUs **802**, where N is equal to, or smaller less than, the other dimension size.
2. Reduces the context table size for coding the syntax of the last coded position: Instead of 6 luma contexts for 16×16 and 7 luma contexts for 32×32 of each type (I, P, B), only half size of contexts, or even smaller than half size of contexts, are now needed for coding of the last subblock position. Also, it is possible that the contexts for 4×4 and 8×8 TU **802** may be used to code the last coded subblock position of 16×16 and 32×32 TUs **802**. In this case, the 16×16 and 32×32 contexts can be completely removed. Finally, for an M×N TU **802** where M≠N and max(M,N) is larger or equal to 16, the same benefits in context reduction can also be possible.

Returning to FIG. **19**, dashed blocks **1906**, and **1910** indicate operations that may be optionally performed in addition to those already discussed. For example, in the foregoing embodiment, a first value "1" was encoded for each subblock **1832** preceding the last significant subblock **1832**L in the scan pattern **1834** having a non-zero coefficient. Any subblock without an encoded first value is therefore known to not include coefficients with non-zero values, and it is therefore unnecessary to code information describing this fact. However, in one embodiment, a second value (such as a "0") can be encoded for each subblock **1832** preceding the last significant subblock **1832**L) having no non-zero coefficients (or all zero coefficients). In this embodiment, the coefficients of subblocks having the second value may be skipped.

FIG. **19** also refers to another optional embodiment in which the position of the last non-zero coefficient **1822** of the last significant subblock **1832**L is also encoded, as shown in block **1906**.

While coding according to the last significant subblock rather than the last significant coefficient saves a number of bits, it also can result in a number of bits trailing the last significant coefficient having a zero value to be coded. For example, in FIG. **18**E, the last significant subblock is subblock **1832**L. If all of the coefficients in this subblock **1832**L are coded (and subsequently decoded), a number of trailing coefficients (e.g. the zero coefficients following the last non-zero coefficient **1822**) will be unnecessarily encoded and decoded.

FIG. **21** is a diagram of the last significant subblock **1832**L of the TU **802**. Coefficient **1822** is the last significant coefficient on the coefficient scan pattern **2002** of the last significant subblock **1832**L, and hence, the coefficients that follow this coefficient **1822** in the coefficient scan pattern are all zeros and need not be coded. Consequently, the encoding of these coefficients can be skipped to save processing and bits. This can be implemented by determining the last significant coefficient **1822** of the last significant subblock **1832**L as the last coefficient along a coefficient scan pattern **2002** within the last subblock **1832**L having a non-zero value, the encoding a position of the determined last significant coefficient of the last significant subblock. In one embodiment, the last significant subblock coefficient value can be expressed in coefficient unit displacements away from the upper leftmost coefficient of the last significant subblock **1832**L. In the example illustrated in FIG. **21**, for example, the last significant subblock coefficient position can be described as last_significant_subblock_last_significant_coeff_x=0 and last_significant_subblock_last_significant_coeff_y=1. Encoding of the TU **802** coefficients of this last significant subblock **1832**L can cease so that the encoding of trailing zero coefficients are skipped.

Returning to FIG. **19** the process of determining the last subblock along a subblock processing pattern that has at least one non-zero coefficient can be accomplished in a number of ways. In one embodiment, this is accomplished using the last_significant_coeff_x and last significant coeff_y values available from previous operations in the encoder **312**. These last_significant_coeff_x and last significant coeff_y values can be used to calculate the last significant subblock **1832**L position. For example, the last significant coefficient **1822** position of the TU **802** can be associated with the last significant subblock **1832**L in Cartesian coordinates by dividing the coordinate of the last significant coefficient **1822** by the associated subblock dimension for each coordinate direction and disregarding the remainder. In the example shown in FIG. **18**D, for example, the last significant coefficient values are (12,10) and the subblock dimensions are 4×4. In this case, the last significant subblock can be determined as (int[12/4], int[10/4])=(3,2), wherein the int[*] function returns the integer resulting from the operation. If the last significant subblock is defined in other ways (e.g. the number of subblocks from the first subblock in the subblock scan pattern), the last subblock may still be mapped from the last significant coefficient position, but more a more complex algorithm may be required.

If the last_significant_coeff_x and last significant coeff_y values are unavailable to map into the position of the last significant subblock position, they may be determined simply by scanning the coefficients using the array scan pattern **1824** or the same subblock scan pattern **1834** and coefficient scan pattern **2002** that will be used in the decoder until the last non-zero coefficient is found. This may be advantageously performed beginning at the last coefficient of the TU **802** in the scan pattern **1824** and scanning until a non-zero coefficient is found, or by beginning at the first coefficient of the TU **802** and scanning the entire TU **802**.

The technique described above can be practiced in other embodiments. For example, instead of determining the last significant subblock and only coding a first value for those subblocks preceding the last significant subblock, the technique may be practiced by scanning the coefficients of the TU **802** and coding a first value for all subblocks having non-zero values (and optionally coding a second value for all subblocks having only zero values), and designating the last significant subblock as the last subblock in the subblock scan pattern that has a coded first value. This technique is useful where a complete L1 level significance map is already available, as the last significant subblock can be readily ascertained from a complete L1 significance map.

FIG. **22** is a diagram illustrating an exemplary technique for decoding TU **802** coefficients that were encoded using the foregoing last coefficient group position technique described above. As described above, the encoding process creates a bitstream **314** that includes syntax for the last significant subblock (e.g. last_significant_subblock_coeff_x and last_significant_subblock_coeff_y). Block **2202** decodes a position of the last significant subblock **1832**L, which is the last subblock having at least one non-zero coefficient along the subblock processing scan pattern **1834**. Depending on how the last significant subblock is encoded, (e.g. as last_significant_subblock_coeff_x and last_significant_subblock_coeff_y, the number of subblocks from the first subblock in the scan pattern, or using a row or column index as described above) this may require computing the last significant subblock position using the information passed in the syntax to account for different scan patterns.

Block **2206** decodes a first value ("1" for example) for each subblock **1832** preceding the last subblock **1832**L along the subblock processing scan pattern that has at least one non-zero coefficient. This can be accomplished, for example, by looping through all of the subblocks **1832** preceding the last subblock **1832**L and decoding the significant_coeff_group flag associated each of the subblocks. This identifies all subblocks **1832** preceding the last significant subblock **1832**L having non-zero coefficients. This can be performed along the subblock scan pattern beginning at the last significant subblock **1832**L and ending at the first subblock **1832**A in the scan pattern, or from the first subblock **1832**A in the scan pattern and ending at the last significant subblock **1832**L.

The coefficients of the last significant subblock **1832**L and the subblocks having the first encoded value (e.g. "1") are then decoded, as shown in block **2210**. Again, this can follow the subblock scan pattern **1834** in either direction, and the scanning of the coefficients within each subblock **1832** can be performed in the coefficient scan pattern **2002**, in either direction. As shown in block **2212**, the decoding of the coefficients within subblocks **1832** not having the significant_coeff_group flag with the first value may skipped, because it is known that the coefficients in these subblocks all have zero values. Further, the decoding of coefficients within subblocks that follow the last significant subblock **1832**L in the subblock scan pattern **1834** (e.g. subblock **1832**P need not be performed, as it is known that such subblocks do not include non-zero coefficients.

As described earlier, it can be inferred that any subblock **1832** not having an associated significant_coeff_group flag of the first value ("1") may be assumed to have all zero coefficients. However in the embodiment described in FIG. **19**, block **1910** encoded a second value for each subblock preceding the last subblock in the subblock processing scan pattern that had all zero coefficients. Hence, the status of such subblocks **1832** is expressly described by the significant_coeff_group flag having a second value ("0"). In this case, the decoding of the coefficients of any subblock **1832** having an associated significant_coeff_group flag having the second value is skipped, so that only those subblocks **1832** associated with the significant_coeff_group flag having the first value will have their coefficients decoded. This is shown in block **2208** of FIG. **22**.

Also as described in block **1906** of FIG. **19**, the position of the last significant coefficient within the last significant subblock **1832**L may be encoded using the last_significant_subblock_last_significant_coeff_x and last_significant_subblock_last_significant_coeff_y variables. If such information is encoded into the bitstream **314**, block **2204** decodes the information so that the position of the last significant coefficient of the last significant subblock is known. The decoding of the coefficients of the last significant subblock **1832**L can begin at this position (e.g. coefficient **1822**) and proceed along the coefficient scan path **2002** in a reverse direction to the first coefficient of the last significant subblock **1832**L or may begin at the first coefficient and end at the last significant coefficient **1822**. Note that this is an improvement from coding and decoding the last significant coefficient of the entire TU **802** array, since the values describing last significant coefficient within a 4×4 subblock will only need to code values between 0-3 rather than 0-16 or 0-32.

While the foregoing has been discussed with respect to the setting of flags, indexes, or other designators to a particular value or state for purposes of passing information or process signaling, the use of the term flag and index is intended to broadly encompass the setting of any designator or other memory artifice for the purpose or reading that designator or memory artifice for later use as described herein.

Hardware Environment

FIG. **23** illustrates an exemplary processing system **2300** that could be used to implement the embodiments of the invention. The computer **2302** comprises a processor **2304** and a memory, such as random access memory (RAM) **2306**. The computer **2302** is operatively coupled to a display **2322**, which presents images such as windows to the user on a graphical user interface **2318**B. The computer **2302** may be coupled to other devices, such as a keyboard **2314**, a mouse device **2316**, a printer, etc. Of course, those skilled in the art will recognize that any combination of the above components, or any number of different components, peripherals, and other devices, may be used with the computer **2302**.

Generally, the computer **2302** operates under control of an operating system **2308** stored in the memory **2306**, and interfaces with the user to accept inputs and commands and to present results through a graphical user interface (GUI) module **2318**A. Although the GUI module **2318**A is depicted as a separate module, the instructions performing the GUI functions can be resident or distributed in the operating system

2308, the computer program **2310**, or implemented with special purpose memory and processors. The computer **2302** also implements a compiler **2312** which allows an application program **2310** written in a programming language such as COBOL, C++, FORTRAN, or other language to be translated into processor **2304** readable code. After completion, the application **2310** accesses and manipulates data stored in the memory **2306** of the computer **2302** using the relationships and logic that was generated using the compiler **2312**. The computer **2302** also optionally comprises an external communication device such as a modem, satellite link, Ethernet card, or other device for communicating with other computers.

In one embodiment, instructions implementing the operating system **2308**, the computer program **2310**, and the compiler **2312** are tangibly embodied in a computer-readable medium, e.g., data storage device **2320**, which could include one or more fixed or removable data storage devices, such as a zip drive, floppy disc drive **2324**, hard drive, CD-ROM drive, tape drive, etc. Further, the operating system **2308** and the computer program **2310** are comprised of instructions which, when read and executed by the computer **2302**, cause the computer **2302** to perform the steps necessary to implement and/or use the invention. Computer program **2310** and/or operating instructions may also be tangibly embodied in memory **2306** and/or data communications devices **2330**, thereby making a computer program product or article of manufacture. As such, the terms "article of manufacture," "program storage device" and "computer program product" as used herein are intended to encompass a computer program accessible from any computer readable device or media.

The processing system **2300** may also be embodied in a desktop, laptop, tablet, notebook computer, personal data assistant (PDA), cellphone, smartphone, or any device with suitable processing and memory capability. Further, the processing system **2300** may utilize special purpose hardware to perform some or all of the foregoing functionality. For example the encoding and decoding processes described above may be performed by a special purpose processor and associated memory.

Those skilled in the art will recognize many modifications may be made to this configuration without departing from the scope of the present disclosure. For example, those skilled in the art will recognize that any combination of the above components, or any number of different components, peripherals, and other devices, may be used. For example, particular functions described herein can be performed by hardware modules, or a processor executing instructions stored in the form of software or firmware. Further, the functionality described herein can be combined in single modules or expanded to be performed in multiple modules.

CONCLUSION

The foregoing description of the preferred embodiment has been presented for the purposes of illustration and description. It is not intended to be exhaustive or to limit the disclosure to the precise form disclosed. Many modifications and variations are possible in light of the above teaching. It is intended that the scope of rights be limited not by this detailed description, but rather by the claims appended hereto.

What is claimed is:

1. A method of processing a transform unit having an array of coefficients, comprising:

(a) determining if all of the coefficients of a portion of the transform unit disposed on a portion of a scan pattern are zero;

(b) setting a flag associated with the portion of the transform unit to a first value if at least one of the coefficients of the portion of the transform unit coefficients disposed on the portion of the scan pattern are non-zero by determining if all of the coefficients of the further portions of the transform unit coefficients disposed on the scan pattern are zero, setting no further flags if all of the coefficients of the further portions of the transform unit coefficients are zero, and setting the further flag only if at least one of the coefficients of the remaining portions of the transform unit coefficients disposed on the remaining portion of the scan pattern is non-zero;

(c) setting the flag associated with the portion of the transform unit coefficients to a second value if all of the coefficients of the portion of the transform unit coefficients disposed in the portion of the scan pattern are zero;

(d) repeating steps (a)-(c) to set a further flag associated with each further portion of the transform unit coefficients disposed on each further portion of the scan pattern; and

(e) encoding the flags and at least a portion of the transform unit coefficients into a coded bitstream.

2. The method of claim **1**, wherein encoding the flags the portion of the transform unit coefficients into the coded bitstream includes encoding only those coefficients associated with a flag having the first value, and skipping encoding of those coefficients associated with a flag having the second value.

3. The method of claim **1**, wherein the array is an N×M array comprising rows and columns and the scan pattern is a wavefront scan pattern that includes a plurality of diagonal scans in a diagonal direction, and each portion of the scan pattern comprises all of the coefficients in one diagonal of the plurality of diagonal scans of the wavefront scan pattern.

4. A method of processing a transform unit having an array of coefficients, comprising:

(a) determining if all of the coefficients of a portion of the transform unit disposed on a portion of a scan pattern are zero, wherein the scan pattern is in a row direction, and each portion of the scan pattern comprises a row of a plurality of rows of coefficients;

(b) setting a flag associated with the portion of the transform unit to a first value if at least one of the coefficients of the portion of the transform unit coefficients disposed on the portion of the scan pattern are non-zero;

(c) setting the flag associated with the portion of the transform unit coefficients to a second value if all of the coefficients of the portion of the transform unit coefficients disposed in the portion of the scan pattern are zero; and

(d) encoding the flags and at least a portion of the transform unit coefficients into a coded bitstream.

5. A method of processing a transform unit having an array of coefficients, comprising:

(a) determining if all of the coefficients of a portion of the transform unit disposed on a portion of a scan pattern are zero, wherein the scan pattern is in a column direction, and each portion of the scan pattern comprises a column of a plurality of columns of coefficients;

(b) setting a flag associated with the portion of the transform unit to a first value if at least one of the coefficients of the portion of the transform unit coefficients disposed on the portion of the scan pattern are non-zero; and

(c) setting the flag associated with the portion of the transform unit coefficients to a second value if all of the coefficients of the portion of the transform unit coefficients disposed in the portion of the scan pattern are zero.

6. A method of processing a transform unit having an array of coefficients, comprising:

(a) reading a flag associated with all of the coefficients of a first portion of the transform unit coefficients disposed on a first portion of a scan pattern, wherein each flag is a member of a last coefficient flag set associated with the transform unit;

(b) decoding the first portion of the transform unit coefficients disposed on the first portion of the scan pattern if the flag has a first value; and

(c) skipping coding of the first portion of the transform unit coefficients disposed on the first portion of the scan pattern only if the flag has a second value, by determining if the flag is a last read flag of the last coefficient flag set and the last read flag has the second value, decoding the portion of the transform unit coefficients following the portion of the transform unit coefficients associated with the last read flag and skipping decoding of the portions of further transform unit coefficients; and

(d) performing steps (a)-(c) for each remaining flag associated with each remaining portion of the transform unit coefficients of each remaining portion of the scan pattern.

7. The method of claim 6, wherein the array is an n×m array comprising rows and columns and the scan pattern is a wavefront scan pattern in a diagonal direction.

8. The method of claim 6, wherein the array comprises a plurality of rows of coefficients, and the scan pattern is in a row direction.

9. The method of claim 6, wherein the array comprises a plurality of columns of coefficients, and the scan pattern is in a column direction.

10. A method of processing a transform unit having an array of coefficients, comprising:

setting a plurality of flags, each flag associated with a portion of the transform unit coefficients disposed on a portion of a scan pattern, each flag set to a first value if at least one of the coefficients in the associated portion of the transform unit disposed on the associated portion of the scan pattern is non-zero, and each flag set to a second value if all of the coefficients in the associated portion of the transform unit disposed on the associated portion of the scan pattern are zero, wherein the transform unit coefficients include a last non-zero coefficient disposed in a last non-zero coefficient portion of the scan pattern, the plurality of flags together comprise a flag set, and the flag set excludes flags associated with the portions of the scan pattern following the last non-zero coefficient portion of the scan pattern;

coding the flag set and the portions of the transform unit coefficients having an associated flag having the first value; and

skipping coding of the portions of the transform unit coefficients having an associated flag having the second value.

11. The method of claim 10, wherein:

the flag set further excludes the flag associated with the last non-zero coefficient portion of the scan pattern.

12. A method of processing a transform unit having an array of coefficients, comprising:

reading a plurality of flags, each flag associated with a portion of the transform unit coefficients disposed on a portion of a scan pattern, each flag set to a first value if at least one of the coefficients in the associated portion of the transform unit disposed on the associated portion of the scan pattern is non-zero, and each flag set to a second value if all of the coefficients in the associated portion of the transform unit disposed on the associated portion of the scan pattern are zero, the transform unit coefficients include a last non-zero coefficient disposed in a last non-zero coefficient portion of the scan pattern, the plurality of flags together comprise a flag set, and the flag set excludes flags associated with the portions of the scan pattern following the last non-zero coefficient portion of the scan pattern;

decoding the coefficients of the portions of the transform unit having an associated flag set to the first value; and

skipping decoding the coefficients of the portions of the transform unit having an associated flag set to the second value.

13. The method of claim 12, wherein:

the flag set further excludes the flag associated with the last non-zero coefficient portion of the scan pattern.

14. A system for processing a transform unit having an array of coefficients, comprising:

a processor; and

a memory, communicatively coupled to the processor, the memory storing a plurality of instructions comprising instructions for:

(a) determining if all of the coefficients of a portion of the transform unit disposed on a portion of a scan pattern are zero;

(b) setting a flag from a last coefficient flag set associated with the portion of the transform unit to a first value if at least one of the coefficients of the portion of the transform unit coefficients disposed on the portion of the scan pattern are non-zero by determining if all of the coefficients of the further portions of the transform unit coefficients disposed on the scan pattern are zero, setting no further flags of the last coefficient flag set if all of the coefficients of the further portions of the transform unit coefficients are zero, and setting the further flag only if at least one of the coefficients of the remaining portions of the transform unit coefficients disposed on the remaining portion of the scan pattern is non-zero;

(c) setting the flag associated with the portion of the transform unit coefficients to a second value if all of the coefficients of the portion of the transform unit coefficients disposed in the portion of the scan pattern are zero;

(d) repeating steps (a)-(c) to set a further flag associated with each remaining portion of the transform unit coefficients disposed on each remaining portion of the scan pattern; and

(e) encoding the flags and at least a portion of the transform unit coefficients into a coded bitstream.

15. The system of claim 14 wherein encoding the flags and the portion of the transform unit coefficients into the coded bitstream includes encoding only those coefficients associated with a flag having the first value, and skipping encoding of those coefficients associated with a flag having the second value.

16. A system for processing a transform unit having an array of coefficients, comprising:

a processor; and

a memory, communicatively coupled to the processor, the memory storing a plurality of instructions comprising instructions for:

(a) determining if all of the coefficients of a portion of the transform unit disposed on a portion of a scan pattern are zero, wherein the scan pattern is in a row direction, and each portion of the scan pattern comprises a row of a plurality of rows of coefficients;

(b) setting a flag associated with the portion of the transform unit to a first value if at least one of the coefficients of the portion of the transform unit coefficients disposed on the portion of the scan pattern are non-zero;

(c) setting the flag associated with the portion of the transform unit coefficients to a second value if all of the coefficients of the portion of the transform unit coefficients disposed in the portion of the scan pattern are zero; and

(d) encoding the flags and at least a portion of the transform unit coefficients into a coded bitstream.

17. A system for processing a transform unit having an array of coefficients, comprising:

a processor; and

a memory, communicatively coupled to the processor, the memory storing a plurality of instructions comprising instructions for:

(a) determining if all of the coefficients of a portion of the transform unit disposed on a portion of a scan pattern are zero, wherein the scan pattern is in a column direction, and each portion of the scan pattern comprises a column of a plurality of columns of coefficients;

(b) setting a flag associated with the portion of the transform unit to a first value if at least one of the coefficients of the portion of the transform unit coefficients disposed on the portion of the scan pattern are non-zero;

(c) setting the flag associated with the portion of the transform unit coefficients to a second value if all of the coefficients of the portion of the transform unit coefficients disposed in the portion of the scan pattern are zero; and

(d) encoding the flags and at least a portion of the transform unit coefficients into a coded bitstream.

18. A system for processing a transform unit having an array of coefficients, comprising:

a processor; and

a memory, communicatively coupled to the processor, the memory storing a plurality of instructions comprising instructions for:

(a) determining if all of the coefficients of a portion of the transform unit disposed on a portion of a scan pattern are zero, wherein the array is an N×M array comprising rows and columns and the scan pattern is a wavefront scan pattern that includes a plurality of diagonal scans in a diagonal direction, and each portion of the scan pattern comprises all of the coefficients in one diagonal of the plurality of diagonal scans of the wavefront scan pattern;

(b) setting a flag associated with the portion of the transform unit to a first value if at least one of the coefficients of the portion of the transform unit coefficients disposed on the portion of the scan pattern are non-zero;

(c) setting the flag associated with the portion of the transform unit coefficients to a second value if all of the coefficients of the portion of the transform unit coefficients disposed in the portion of the scan pattern are zero; and

(d) encoding the flags and at least a portion of the transform unit coefficients into a coded bitstream.

19. A system for processing a transform unit having an array of coefficients, comprising:

a processor; and

a memory, communicatively coupled to the processor, the memory storing a plurality of instructions comprising instructions for:

(a) reading a flag associated with all of the coefficients of a first portion of the transform unit coefficients disposed on a first portion of a scan pattern, wherein each flag is a member of a last coefficient flag set associated with the transform unit;

(b) decoding the first portion of the transform unit coefficients disposed on the first portion of the scan pattern only if the flag has a first value; and

(c) skipping coding of the first portion of the transform unit coefficients disposed on the first portion of the scan pattern if the flag has a second value by determining if the read remaining flag is a last read flag of the last coefficient flag set and the last read flag has the second value, decoding the portion of the transform unit coefficients following the portion of the transform unit coefficients associated with the last read flag, and skipping decoding of the portions of further transform unit coefficients; and

(d) performing steps (a)-(c) for each remaining flag associated with each remaining portion of the transform unit coefficients of each remaining portion of the scan pattern.

20. The system of claim **19**, wherein the array is an n×m array comprising rows and columns and the scan pattern is a wavefront scan pattern in a diagonal direction.

21. The system of claim **19**, wherein the array comprises a plurality of rows of coefficients, and the scan pattern is in a row direction.

22. The system of claim **19**, wherein the array comprises a plurality of columns of coefficients, and the scan pattern is in a column direction.

23. A system of processing a transform unit having an array of coefficients, comprising:

a processor; and

a memory, communicatively coupled to the processor, the memory storing a plurality of instructions comprising instructions for:

setting a plurality of flags, each flag associated with a portion of the transform unit coefficients disposed on a portion of a scan pattern, each flag set to a first value if at least one of the coefficients in the associated portion of the transform unit disposed on the associated portion of the scan pattern is non-zero, and each flag set to a second value if all of the coefficients in the associated portion of the transform unit disposed on the associated portion of the scan pattern are zero, wherein the transform unit coefficients include a last non-zero coefficient disposed in a last non-zero coefficient portion of the scan pattern, the plurality of flags together comprise a flag set, and the flag set excludes flags associated with the portions of the scan pattern following the last non-zero coefficient portion of the scan pattern;

coding the portions of the transform unit coefficients having an associated flag having a the first value;

skipping coding of the portions of the transform unit coefficients having an associated flag having the second value; and

encoding the flag set and at least a portion of the transform unit coefficients into a coded bitstream.

24. The system of claim **23**, wherein:

the flag set further excludes the flag associated with the last non-zero coefficient portion of the scan pattern.

25. A system for processing a transform unit having an array of coefficients, comprising:

a processor; and

a memory, communicatively coupled to the processor, the memory storing a plurality of instructions comprising instructions for:

reading a plurality of flags, each flag associated with a portion of the transform unit coefficients disposed on a portion of a scan pattern, each flag set to a first value if at least one of the coefficients in the associated portion of the transform unit disposed on the associated portion of the scan pattern is non-zero, and each flag set to a second value if all of the coefficients in the associated portion of the transform unit disposed on the associated portion of the scan pattern are zero, wherein the transform unit coefficients include a last non-zero coefficient disposed in a last non-zero coefficient portion of the scan pattern, the plurality of flags together comprise a flag set, and the flag set excludes flags associated with the portions of the scan pattern following the last non-zero coefficient portion of the scan pattern;

decoding the coefficients of the portions of the transform unit having an associated flag set to the first value; and

skipping decoding the coefficients of the portions of the transform unit having an associated flag set to the second value.

26. The system of claim **25**, wherein:

the flag set further excludes the flag associated with the last non-zero coefficient portion of the scan pattern.

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